Blott Mathews Challenge
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Energy For Everything

Portsmouth College
2017-2018

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Introduction
About us

The College

Ben Searle, Science Learning Technician, Portsmouth College

We are an independent FE college on the South Coast and have gained several nominations and won awards for our innovations in teaching and learning, the most recent success being the 2017 AOC Beacon Award for "Effective use of Technology in Further Education" for our college-wide student iPad scheme. We also use Google Classroom and Drive as a key part of learning and resource sharing. The structure of the day at Portsmouth College has gained positive attention, as we only have two teaching periods per day, starting at 9:50 and ending at 16:00. The timings are very popular with students in the area, and the longer lessons mean that in science especially, we can tackle bigger concepts and do more involved practicals in a single class.

The College has taken part in the Blott Matthews Challenge since it began in 2015, and from a staff perspective, the teams of students have got better year on year. It is amazing to see what a group of students are able to create with such a wide stretching and scientifically relevant brief each year, especially with less and less mentoring from us each time. This year, the team has entirely managed and executed this project on their own, aside from a little advisory input at the start to get the creative gears turning and the team working together fluidly. As our own technician jobs have demanded more time from us and prevented us from being able to attend progress meetings, this team has really stepped up to the mantle and organised their own meetings, group chats, and targets; and I know they will flourish at university (or whatever they decide to move on to next in life) with the skills they have learnt from this project. Congrats team!

Sean Cleary

Solar technologies

I am currently a student at Portsmouth college studying chemistry, biology and history. I care about the environment and enjoy sciences (kinda) so this challenge was a win win project for me. Also, I like trains.

Jonty Bassil

Carbon Capture

My friends tell me that my bios are always lit which is a pretty cool feeling actually… The Blott-Mathews challenge has been an amazing experience, with amazing people. I feel that my chosen classes; Physics, Maths, and Computer Science have really helped me to be as efficient and motivated as possible. As well as college, I do Judo and Air Cadets, and love making jokes, most of which tend towards the controversial side. I wasn't allowed to put one in.

Izah Fatima

Public transport

My name is Izah Fatima. I'm a AS level student at Portsmouth College. As for my A-level courses, I do Maths, Chemistry and Biology. I've always loved these three subjects and in the future I hope to achieve degree on a science based subject such as Chemistry, hopefully from a top university in the UK. I chose to participate in Blotts Matthews challenge because I was interested in how a carbon neutral city would work and I wanted to learn and develop new skills.

Abraham Kattumattathil

Industrial Transport

What can I say about myself? Not much really, apart from the fact that I am amazing, just joking. I am a determined, creative, smart young man who likes to be challenged, which is the main reason why I entered this competition, it seemed interesting and new to me. I was able to bring forward knowledge from the subjects I study (maths, physics, chemistry) in to the research. This has been an amazing experience for me which I will like to take forward in my higher studies.

Ashraf Hussain

Hydroelectric power and Distribution

Being a biology, chemistry and mathematics student, this was one of the most ambitious projects I've ever been involved in. I've learnt that Science is really like a language and Blott-Matthews has helped me learn it. I've really enjoyed learning about the real-life applications of all the science I come across in class.

Grace Baker

Personal Transport

I'm currently a student at Portsmouth College; studying biology chemistry and maths. I aspire to be a medicine researcher and help discover new treatments for life threatening diseases. This project has helped my develop my skills formatting reports and Stick to deadlines. Thank you for the opportunity. I like trains.

Evelyn Murray

Nuclear Technologies and Domestic Energy Saving

The environment and poorly timed political jokes are two things I really enjoy so I'm really glad I got the opportunity to work on this project (I apologise in advance for my terrible sense of humour). Currently I'm studying Chemistry, Biology, Maths and Further maths so it was nice to have a chance to apply some of my subjects to a real life situation and learn about new technologies that may be implemented in the near future. Other than science my hobbies include martial arts, binge-watching Sherlock on Netflix and spending money I don't have so at the very least the challenge has got me to find a more constructive use of my time!

Solent city Brief

Achieving Carbon Neutrality

Aims and strategies

Aim

To develop a concept design for the combined energy supply and transport for a carbon neutral powered city covering the region bounded by and including Portsmouth, Southampton and the region south of the M27 with a population of 2 million, considering cost effectiveness and timescale of implementation. Key features of the design must include:

- **Energy-** sourced from any fuel or renewable source providing not net CO_2 to the atmosphere with considerations to power generation and storage. It may be based inside or outside the city and be centralised or distributed but must be sufficient to meet the peak energy requirement of the city at any time of day. Solution must include proposals for supplying critical services if production was to fall to 20% of capacity.

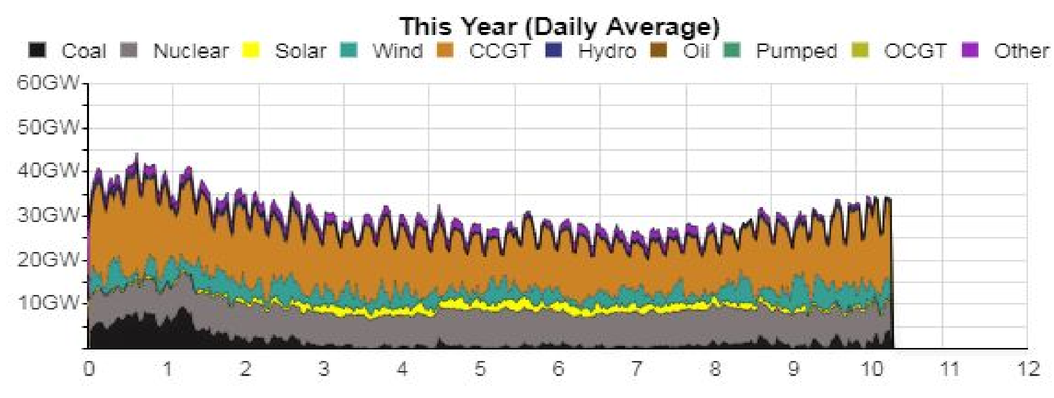
- **Transport-** Must be considered for land sea and air within the city and meet the demands of visitors and residents alike. They must also comply with the specifications for carbon neutrality detailed in the energy section and be supplied in the event that 80% of power supply is lost. Adaptations that need to be made to infrastructure to implement the technologies must be detailed in the report.

- **Implementation-** An estimate to the overall equipment, infrastructure, installation and commissioning costs of the energy supply system and transport system accounting for set up and running costs must be made along with a plan for implementation

Requirements and Considerations

Total demand for City

Based on Uk 2015 requirements



Initial Requirements

City

- **Population:** 2 million[1]
- **Area:** 92.06 km^2 [2]

Energy requirement

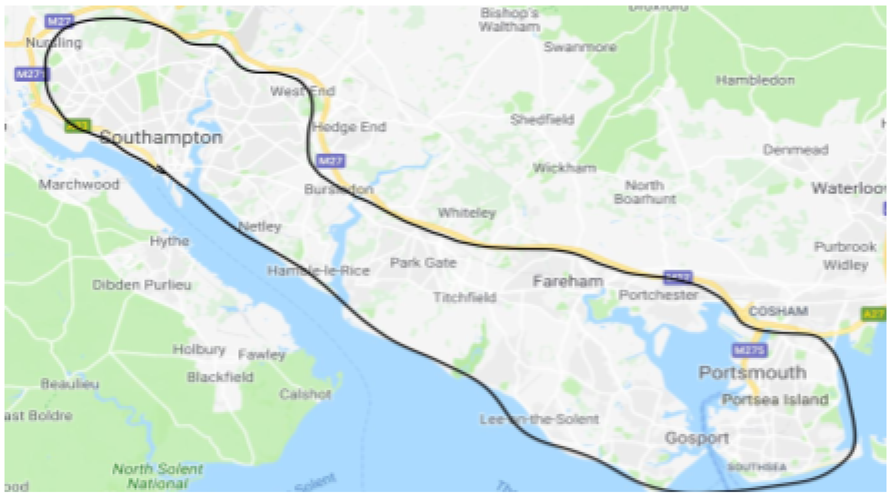
- **Total: 4,265,302 MWh** (per year) [3]
- **Per sector:**
- Domestic- 1,364,867 MWh (per year) [4]
- Industrial- 810,407 MWh (per year) [4]
- Transport- 1,578,162 MWh (per year) [4]
- Other- 511,836 Mwh (per year) [4]

CO2 emissions

- **Total: 14,260,000 tons** [5]

Overview of design

Our plan for solent city



Plan Overview

We have broken down our plan to achieve carbon neutrality into 4 key sectors each assessing the most effective new and existing technologies to achieve a net carbon consumption of zero.

- **Section 1- Energy:** looks at using renewable sources and nuclear fuels to meet the 4,265,302MWh per year requirement of the city. We have opted for a combination of Nuclear solar and Hydroelectric detailed below.
- **Section 2- Transport**: Focuses on implementing new transport systems both domestically and industrially to decrease dependency on polluting vehicles through utilizing our low carbon methods of energy production. Public transport as opposed to individual vehicles is encouraged.
- **Section 3- Domestic Infrastructure:** Based on eliminating use of gas for space heating and developing domestic infrastructure to decrease energy consumption and consequently reducing carbon footprint.
- **Section 4- Carbon Capture:** Using both developed 'CSS' cycles and rising technology to eliminate remaining carbon output of transport sector and generation of fuel.

Energy

Since the demand for electricity in solent city we are unable to rely solely on renewable sources to comfortably meet demands, particularly during peak periods. Insteaded we have opted to use half renewable sources, solar and hydroelectric and half nuclear power despite the extra expense. Locations and capacity are detailed in the table below.

Energy source	Percentage of total power	Capacity (MWh per year)	Location	CO2 emissions	Cost
Nuclear	50%	2190,000	King George V docks Southampton	6349 tonnes	£1.33 billion
Hydroelectric	20%	876,000	Meon Valley	876 tonnes	£1 billion
Solar	30%	1,470,000	Domestic housing	3822 tonnes	£2.875 billion

We have opted to produce over the energy requirements for the city to account for any extra electricity required to power electric transport to reduce carbon emissions from the transport sector.

To save on costs and minimise disruption energy sources will be connected to the existing grid.

Transport

While, many technologies are already available, or currently being developed in an effort to pave the way to a greener society the transport sector proves to be the most difficult sector to achieve carbon neutrality. Consumer choice limits the ability to fully erase the use of polluting vehicles thus we have chosen to focus on improving public transport to deter people from the use of cars altogether. Hydrogen fuel cell cars will be promoted with a hope their current price decreases as technology advances . Electric Ships will also be implemented to reduce carbon emissions of the solent . We plan to rely on the following methods for transport:

- Public: Monorails, Boris bikes, Bus Rapid Transit
- Industrial: Electric ships

With a total cost of : £34 billion

Reduction in carbon emissions: 1,697,500 tonnes

Domestic

Housing has been modified based on conventional victorian properties found throughout a majority of the solent region, insulation is assumed to be virtually nonexistent and so all houses have been retrofitted to minimise heat loss. Heating systems have also been switched to renewable sources such as ground source heat pumps, which benefit from the government's feed in tariff and skirting heating systems will be implemented as to distribute the heat more efficiently. Electricity consumption has been minimised through simple solutions including grade A+ appliances and Led bulbs along with tubular daylighting devices to optimise both new technologies and natural resources. Solar panels with storage batteries should produce sufficient electricity to cater for domestic demand, however some energy may be used to account for space heating since ground source heat pumps do require electricity to function. Solutions and costs are detailed below.

Area	Cost
Lighting	£250 million
Appliances	£95 million
Insulation	£1.955 billion
Hot water	£37.5 million
Heating distribution and generation	£2.225 billion
Electricity Generation	£2.875 billion
Total	**£7.45 billion**

Although costly we predict this will reduce our overall CO_2 emissions by over 2.8 million tonnes before new energy generation methods are even implemented.

Carbon Capture

Obviously even with using incredibly low emission methods of energy generation, reducing consumer consumption of electricity and implementing new transport mechanisms it would be impossible to ensure carbon neutrality in city since petrol and diesel vehicles will still be in use for sometime. To combat this we have chosen two methods of carbon capture we hope will have sufficient capacity to store remaining emissions. We have chosen to rely on commonly used ‘CSS’ cycles and trial a new form of storage using E-Coli bacteria in hope to pilot new innovations in carbon capture and storage. We should have potential to store well over 45 million tonnes CO_2 if necessary.

Energy

Generation and storage

Hydroelectric Nuclear and Solar Power

Plan Overview

Before any modifications are made to the infrastructure of solent city, the region requires 4265 TWh of energy per year to operate, predominantly consumed by the transport sector. It is vital our energy supply is able to meet this demand for the duration of renovations as to achieve carbon neutrality as quickly as possible by reducing reliance on the national grid. Due to this we felt like relying heavily on renewable sources such as wind, solar and tidal power proved to be too unreliable to distribute power to such as large scale city as possible surges in demand or non optimal conditions decreasing efficiency were too likely. Biofuels were also rejected due to the heavily industrialised landscape of the region making production of fuel sources inefficient. Outsourcing fuels would require use of transport lorries producing CO_2 thus ceasing to eliminate the issue of greenhouses gases. Over the years the Uk has already seen a rise in Food prices due to inflation and the production of biofuels only threatens to increase this affecting quality of domestic life. Accounting for all of these considerations we have chosen to split our energy production in the following proportions:

- 50% Nuclear power
- 20% hydroelectric power
- 30% Solar

We feel this provides the best options for cheap yet reliable energy as excess energy from all of these methods is able to be easily stored to cope with sudden surges in demand associated with modern life. By utilizing as range of centralised and large scale distributed supplies we aim to meet the needs of the city as cheaply and efficiently as possible, while still ensuring complete carbon neutrality.

Nuclear power
Molten salt reactors

New innovations in nuclear power

50% of total power supply

Benefits of nuclear power

With the detrimental effects of fossils fuels becoming ever more alarming huge progression is occurring in field nuclear technologies in order to help the plant find an energy source that is both sustainable and suitable for the needs of the 21st century. While renewable energies like solar power and wind farms promise cheap energy with minimal damage to our environment, their lack of reliability creates concern regarding their use for large scale energy production - particularly for Westernised societies such as our own. In our modern era can you imagine anything worse than not being able to laugh at Gemma Collins at the Brit awards because it wasn’t windy enough to meet peak demand? Whilst a current lack of new developments in nuclear technologies mean they are often disregarded as ‘uneconomical’ - because of course spending thousands of pounds worth of bonuses to politicians, who have failed to fix the issue of rising carbon emissions is a much better use of our money - innovative new types of reactors promise to lower the cost of nuclear power making it attainable to all countries, possibly even post-brexit Britain.

Successful implementation

Despite its current expense, countries on our own doorstep are already reaping the benefits from widespread use of nuclear power. France produce an enormous 77% of their electricity from nuclear power[1] and let's face it they’re no worse off than us economically (both economies estimated to be worth approximately $42,500 per capita[2]), so why is there so much controversy surrounding Nuclear power? Although, yes, it is more expensive than traditional coal, it has far more environmental benefits. In 2014 France generated 1585 twh energy[3] compared to the uk's 1280 tkw[3] yet just 4.37 tonnes CO2 per capita[4]- 1.62 tonnes less than the UK[4]. While obviously much work is still needed to establish carbon neutrality, the use of nuclear power allowed France to triumph over us in the race for a greener society.

Economic issues:

But back to cost, if nuclear power is so extortionate then how come existing nuclear plants are one of the cheapest sources of electrical power production in the United States[7] and France boasts one of the lowest electricity prices in Western Europe[8]? The challenge for nuclear is the same as it has been over the last several decades - set up costs. In order to be economically viable, nuclear energy will need to become much cheaper. This will require advanced nuclear designs that can be built for less and operate safely.

Salt cooled thermal reactors:

A new generation of power

With new designs emerging it seemed pointless to rely on outdated nuclear reactors to provide Solent City with power - you wouldn't buy an iPhone 4 for £600 when you could have an iPhone X for £300.

Instead we chose to use safe, innovative technologies which promise reliable nuclear power for a fraction of the cost. Salt-cooled thermal reactors come in a large variety of configurations, all of which employ slow neutrons and some type of salt for the primary and/or secondary coolant, such as molten fluoride salt or in some cases the fuel is a liquid either dissolved in or adjacent to a salt coolant.

Theory

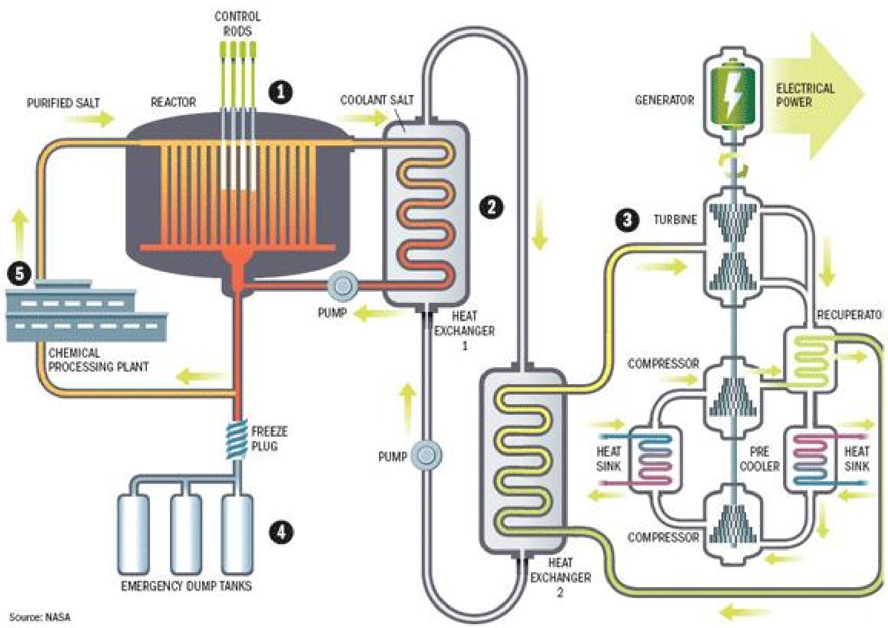
Transatomic Power is developing a very simple molten salt reactor to burn spent nuclear fuel, thorium or low enriched uranium. Their design, known as the Waste-Annihilating Molten Salt Reactor (WAMSR) and could possibly further reduces the cost of nuclear power by using recycled fuel[5]. Molten salt reactors work on the basis that liquid salts have a higher specific heat capacity to water making them more thermal effient and so cheaper to run. Oxbridge conducted several studies throughout 1960s proving not only are these reactors feasible but also cheaper than standard nuclear power[6].

How they work

Molten salt reactors operate in a similar way to regular light-water nuclear reactors using fission of large atoms to generate energy.

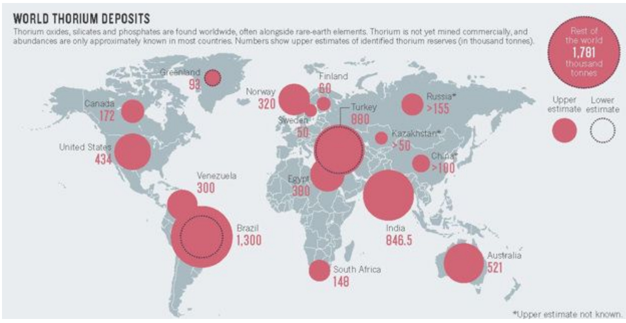
In nuclear power plants, neutrons collide with fissile atoms, splitting them. This split releases neutrons from the atom that in turn collide with others, causing a chain reaction. This chain reaction is controlled with "control rods" that absorb neutrons. In the core of nuclear reactors, the fission of nuclear fuel releases energy that heats water that is then used to spin turbines, connected to generators in order to produce electricity.

The fundamental difference between standard nuclear generators and molten salt reactors is that molten salt reactors reaily on liquid fuels, often a combination of uranium 233, and thorium dissolved in molten lithium fluoride as opposed to purely running on solid uranium[5]. This is because thorium on its own is not fissile so uranium is required to initiate fission. As fission occurs heat released free neutrons begin converting thorium into uranium 233. Heat is then transferred to another loop of molten salt, not containing nuclear materials. This heat is used to heat helium gas, not water, which turns a turbine attached to a generator.



How molten salt reactors work [21]

Fuel:



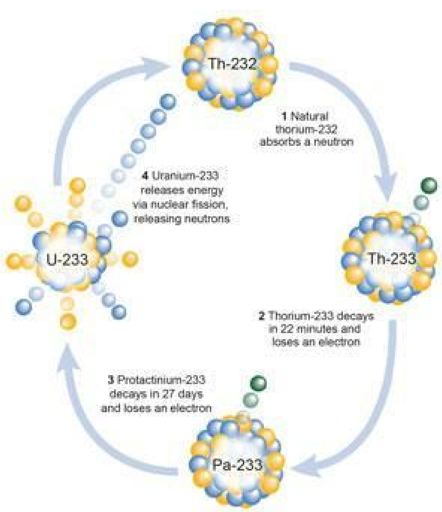
World Thorium Deposits [22]

Thorium is 3 times more abundant than uranium promising lower running costs[9]. Soil contains an average of around 6 parts per million (ppm) of thorium, meaning there is an abundance readily available for extraction[9]. Thorium is basically the spare change that fell down the back of your sofa - forgotten but incredibly useful.

Although the element itself is not fissile when used in a Liquid Fluoride Thorium Reactor (a particular type of molten salt reactor), it can potentially be a source of nuclear power that is cheaper, cleaner, and safer compared uranium.

In nature thorium typically exists as Th-235, which is fairly stable and considered a fertile isotope, however when Th-232 absorbs a neutron it transforms into U-233, a fissile isotope. Subsequently, this process can be used to create U-233 from Th-232 and also maintain the U-233 nuclear decay chain reaction. In a molten salt reactor thorium is dissolved in liquid salts and as these salts are very stable has the ability to transfer heat from the core to the generator.

To make thorium fissile it undergoes some alterations in the nuclear reactor. The reactor is separated into two parts: the core and the thorium blanket. In the core, uranium reacts to produce neutrons. The excess neutrons exit the core and fuse with thorium atoms in the blanket. When the thorium in the blanket transmutes into uranium, it is sent back to the reactor to fission. This system allows the reactor to “breed” fuel creating fissile uranium from the previously thorium in the reactor’s blanket.[10]

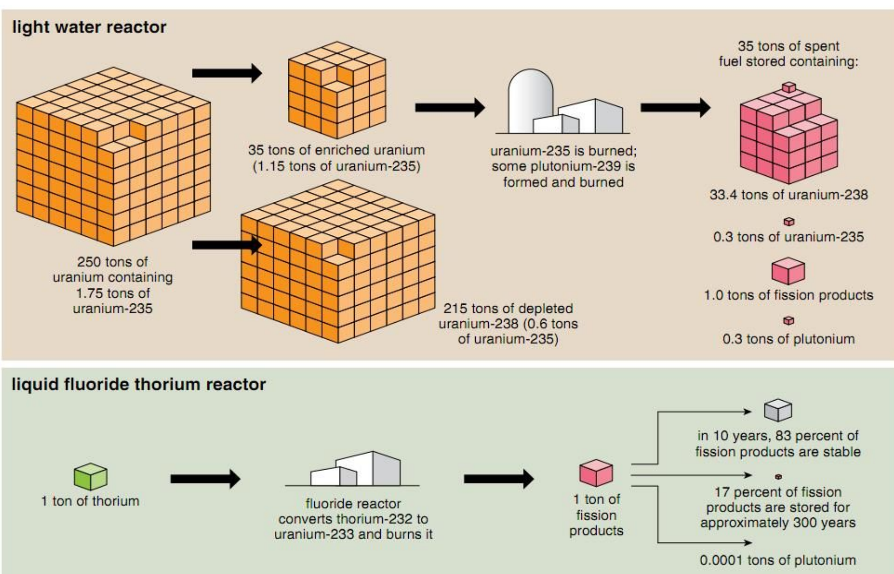


Thorium Fuel Cycle[23]

There are many benefits to using thorium in place of uranium for example it has higher thermal conductivity and lower thermal expansion than uranium, as well as a much higher melting point making it more efficient than uranium and increasing the life of power plants. In nuclear fuel, fission gas release is much lower in thorium and so less nuclear waste is generated making it safer on top of reducing costs associated with the disposal of nuclear waste.[10] In Fact after just 10 years 83% fission products are stable and can be sold generating a new source of income for solent city[11]. Both fuels generate equal amounts of energy (200 MeV per fission of one nucleus[12]), so I can confidently conclude thorium would adequately reach peak demand. Because molten salt reactors are also much more efficient than conventional nuclear reactors they require less fuel to operate. In thorium cycles more neutrons are released per neutron absorbed than in the fuel in a traditional type of reactor, therefore fuel is reprocessed so reactors could be fueled without mining any additional U-235 for reactivity boosts, which means the nuclear fuel resources on Earth can be extended by 2 orders of magnitude and fuel costs would decline as a lower quantity is needed[10].

Waste:

Another source of economic savings is in disposal of nuclear waste; salt cooled reactors would be able to fission the majority of the thorium fuel and transuranic waste. In fact, molten salt reactors are 98% fuel efficient unlike the typical 5% of standard nuclear plants[10]. Also, the only waste that would need to be stored is fission products, meaning they are far less dangerous. One particular type of molten salt reactor, the waste-annihilating molten salt reactor, has the capacity to produce just 254 kg of waste a year vs 20 tonnes produced by a standard nuclear plant[13]. Additionally this waste only needs to be safely stored for a fraction of the time, as little as 200-300 years, unlike upto 3000,00 years in standard plants[14]. This reduces the disposal costs significantly.



Fuel Disposal [24]

Construction

In addition to providing safe energy, molten salt reactors can be just ⅕ of the size of other nuclear power stations[15] making them feasible for our small city. Building costs can be further reduced by steel plate reinforced concrete, an innovation that has reduced construction time by 10 months in Korea[16]. This technique makes the concrete structure stronger, more flexible, and able to withstand even airplane crashes and earthquakes. Moreover, the reactors can be up to 46% thermal efficient, compared to 33% for coal and provide opportunities to recycle heat energy into useful energy to heat homes[5].

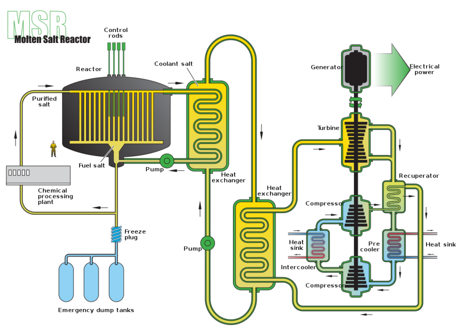
Materials used in the design are also relatively cheap and readily accessible[15]. The design currently proposed by researchers in the UK uses nickel superalloy boiling tubes, which are already in use in coal powered plants. They have low corrosion in molten salts up to 750°C - the typical operating temperature of a plant - and have excellent manufacturability, meaning they are cheap to make, easy to produce and also very safe[15]. Using readily available materials will limit construction time and cost significantly. Molybdenum fuel tubes are used to transport nuclear fuel around the reactors since they are thermodynamically resistant to molten salts they again ensure the design is safe and functional[15]. Moreover they have far lower neutron damage than nickel or carbon helping to solve issues arising from graphite tubing used in the core of the original molten salt reactor design. By again relying on materials already being produced construction is again made more efficient.

Safety:

In order to prevent a repeat of Chernobyl we took great consideration over the safety of using a model of nuclear reactor not already in commercial use. However: non fuel cladding; liquid fuel eliminating risks from fuel melting; and FLiBe coolants, which slow reaction if removed and have higher neutron absorption to reduce fuel burnt, ensure the reactors are safe to use. What's more, due to its high boiling point, fluoride salt coolant remains liquid at low pressures and high temperatures. This allows the reactor vessel to be non-pressurized so does not risk explosions and would not require large containment infrastructure. As the fuel salts work at normal atmospheric pressure, a breach of the reactor containment vessel would simply leak out the liquid fuel which would then solidify in as it cooled, therefore no toxic fuel would be released even if significant damage was caused to the reactor resulting in a fuel leak. Additionally, radioactive byproducts of fission like iodine-131, caesium-134 and caesium-137 are physically bound to the hardened coolant and do not leave the reactor site so have no risk of contaminating local water supplies[5].

Previous tests have also shown when FLiBe salt was used to transfer heat through the secondary loop of the Molten Salt Reactor Experiment, no corrosion was detected and negligible contamination of the salt was found after four years of operation meaning the reactors are likely to last safely for long periods of time[5].

Safety Features of LFMSRs [26]



Another safety innovation unique to molten salt reactors is a plug designed to melt at excessive temperatures, releasing the reactors components into a ‘dump tank’. As the salt in the core of the reactor is liquid it can be removed while the reactor is working, thus the reactor can continue to operate, preventing power loss and avoiding meltdowns. This system creates unparalleled safety as it means molten salt reactors are walk-away safe. They cannot melt down as conventional reactors can because they are molten by design. An operator cannot even force a molten salt reactor to overheat. If for some reason the reactor did overheat, the freeze-plug would drain the liquid fluoride salts into the emergency cooling tanks where it would cool and solidify. No operator interaction nor even emergency backup power is needed for this to happen. Even Homer Simpson could safely operate this power plant.

Lastly, the fuel and coolant salts are chemically inert, and non-firing or explosive with air or water thus provide little damage to the reactor vessel meaning it's unlikely to break down, and even if it did the result would not be detrimental to the surroundings as there is no risk of explosions.

Practicality

Salt cooled reactors are close to meeting all of the key criteria identified to achieving substantial cost reductions relatively quickly; it's thought they may be ready for commercialization by 2020 - probably sooner than Theresa May will achieve a trade deal with the EU.

Potential power output

Molten salt reactors have been proposed in a range of power outputs from just 5MWt to large scale 4000 MWt[16] reactors suited to coping with peak demand in heavily populated, westernised countries. To put this in perspective the UK had a potential generating capacity of 6118 MWe in 2015[17], so just one of these reactors could almost reach the energy requirements for our entire country. Proportionally Solent City requires approximately 187.9 MWe to meet the demands of its 2 million population thus we have decided on a moderate 250 MWe Liquid Fluoride reactor to provide sufficient power to solent city in conjunction to minimising the risks of using a new method of energy generation. These smaller scale reactors are able to rapidly adjust their power output and subsequently are ideal for use as peak or back up reserve power if required. They are also renowned for being inexpensive and quick to build so there is potential to construct more to meet the UK's growing energy requirement in the future.

Current concerns

Since molten-salt reactors have not yet been utilized by the industry, there is a potential for unforeseen issues with both operating the reactors and safety. However, if careful considerations are made it's possible to dramatically minimise such risks.

Firstly, salt coolant can be corrosive to metals, weakening the core structures and depositing corrosion products in cold regions, leading to potential plugging. Fortunately, corrosion can be significantly minimized if salt devoid of all impurities is used, but manufacturing pure salt can be expensive - not ideal since the aim was to supply cheaper nuclear power. However, when FLiBe salt was used in the late 1960s to transfer heat through the secondary loop of the Molten Salt Reactor Experiment, no corrosion was detected in the loop and negligible contamination of the salt was found after four years of operation[5]. By using liquid fuels as well as coolant, this risk can be drastically reduced, aided by our choice of highly-corrosion resistant materials during construction.

The uses of lithium in fuels also raises another issue as it leads to the production of tritium, a radioactive and extremely mobile particle[18]. Specialised sodium fluoroborate intermediate salt[18] maybe used to capture this but close observations must be kept on surroundings to prevent damage to the local environment.

Typical graphite modifiers must also be avoided in this design, since high temperatures and radioactive salts mean the will easily react therefore must be replaced regularly. We can attempted to eliminate this problem by refraining from using graphite in our reactor entirely.

An onsite chemical plant is also required to manage core mixture and remove fission products. Instead of attempting to avoid this we have chosen to view it as an advantage since it will help to generate more employment opportunities within the city.

Even after considering all the risks involved, there are still an abundance of advantages that vastly outweigh the potential disadvantages and after all, how will we ever find a solution to our current energy crisis if we never implement any new technologies?

Summary of cost

Costs associated with nuclear power come from 4 key areas: fuel costs; cost of maintaining plant; capital costs; and the expense of decommissioning, including the disposal of nuclear waste. The final thing to consider is the energy output of the plants to determine whether the plant is economically beneficial. To help put the price of molten salt reactors in context it's important to compare them to pre-existing nuclear power to highlight the reduction.

Starting with fuel, the World Nuclear Association estimates the production of 1 kg of enriched uranium ready for use in a nuclear reactor requires 8.9kg of U_3O_8 [19]. The cost of processing this ore (accounting for cost of mining ore, conversion enrichment and fabrication) totals to £1900. 1 kg of fuel can produce 360,000 kWh so the kWh cost of uranium fuel is £0.53 per kWh[19].

The cost of operating and managing a plant can be extortionate, with employee salaries, licence fees, contractor services and other domestic necessities estimated to total around £403,200 or £1.12 per kWh[19].

Capital and decommissioning costs are the final costs to account for. Capital costs are the cost of building a new plant (calculated without taking into account interest during the building period). The decommissioning cost on the other hand is the cost of disassembling a reactor at the end of its life. This includes waste disposal and properly storing the hazardous nuclear waste. For a typical plant with 1,100MW reactors that give the plant a power output of 2,200MW, the total capital costs are around £8.7 billion and decommissioning costs are approximated at anywhere between £225 million and £370 million [9] (for these calculations I assumed £370 million). Assuming a 60 year life span and a 6% annual discount rate, the total cost of the project is amortized to £3.2171 $\times 10^{10}$. A generator of this size could generate 1.08 $\times 10^{12}$ kWh over the duration of its life bring total capital and decommission costs to £2.98 per kWh[9].

Overall this brings the cost of nuclear power to approximately £4.63 per kWh. Compared to the average cost of generating electricity through coal, £0.14p per kWh [20], this is extortionate and it's easy to see why nuclear energy is often rejected and a clean source of energy. However it is possible to attain cheaper energy through the use of molten salt reactors.

The cost of building a LFTR can also be estimated by analyzing the Oak Ridge National Laboratory's Molten Salt Reactor Experiment (MSRE). This experimental reactor was built in 1962 and aimed to show that a liquid fluoride thorium reactor was feasible. They concluded in 1969 when the study was conducted to cost of building a molten salt reactor was just £88,425,234[9], therefore around £1.333 billion in 2012 once considering inflation. Assuming the same life span and annual discount rate, although molten salt reactors are predicted to last longer than conventional reactors, the total capital costs are £8.162 x10^7. Operating costs in 2012 are estimated to cost just £8.07 x10^6,[9] bringing total annual cost minus fuel to just £8.970 x10^7. The molten salt reactor proposed by Oxbridge was a 1000 MW reactor, which due to the molten salt coolant can operate continuously throughout the year without the need for refueling, therefore in a year it can generate up to 8,760,000,000 kWh. This means total annual cost (minus fuel costs) divided by potential power output equates to only £0.01 per kWh.

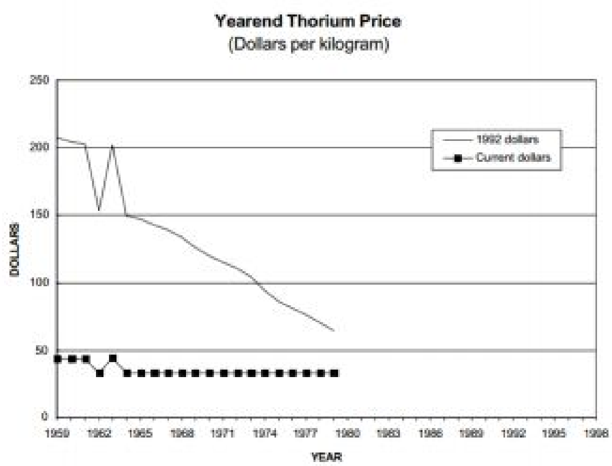


Figure 18: Price of thorium since 1959. Prices dropped so low that it was no longer kept track of after 1978.

Thorium Fuel Prices [9]

Fuel is the last expense to be considered. In 1960 this was estimated to be just £0.03 per kWh[9], however a huge decline of the price of thorium in 1980 means that the price of thorium has not been reliably recorded since. If we were to extrapolate the cost of thorium assuming a continuing trend in decrease in price, we can conclude that fuel cost is negligible. As thorium has an energy yield of 11,000GWh/MT, just 0.0909Kg is required per kWh, so fuel costs would be too low to include in our calculations, bringing total cost of energy from a molten salt reactor to just £0.01 kWh.

Cost per kWh	**Light-water reactor**	**Molten-salt reactor**
Operating costs	£1.12	£0.0094
Capital and decommissioning costs	£2.98	£0.0009
Fuel costs	£0.53	Negligible
Total	£4.63	£0.013

Cost comparison for LWR/MSR

Implementation

Despite molten salt reactors not being widely used to generate electricity, an abundance of promising prototypes following the Oxbridge study demonstrate their promising future in nuclear power. Due to their high reliability, efficiency and unparalleled ability to meet peak demand we have chosen to generate approximately 50% of Solent City's power on nuclear fuel from molten salt reactors, and eliminated the concerns often associated with the economics of nuclear fuel. Despite their capacity to provide energy on a far larger scale we have opted for smaller reactors, with the intention of generating our electricity from a range of sources to utilize all natural resources Solent City has to offer and minimising the detrimental effects to society if one of our power sources was to shut down. Even with the clear advantages to molten salt reactor, the lack of previous implementation means it would be too risky to rely on them for 100% of Solent City's power in case of unforeseen issues.

Location

After carefully considering 6 possible locations in the region we have decided that situating the plant in a remote region of Southampton docks originally the site of King George V dry docks would make the ideal location for the construction of our new power plant as it would minimise the potential hazards of toxic waste emitted from the plant. With molten salt reactors being relatively small in comparison to standard nuclear reactors, it would provide us with a substantial exclusion zone to limit risks of tritium gas produced as a byproduct, giving us ample time to evacuate the area before a leak posed a threat to public. Additionally, although molten salt reactors don't require a water coolant we felt it important to place our reactor in close proximity to a water source to to help cool reactor in case of a melt down and provide sufficient access to water for everyday operations in the plant in order for it to operate at maximum efficiency. Although there will be an obvious loss of trade when the port is removed we believe there is potential to relocate it on the River Itchen or Test, and in the meantime jobs will be available in the plant minimising unemployment.

Conclusion

Location	East of King George V docks Southampton
Power output	250 MWh (with potential to increase in the future)
Total percentage of energy generation	50%
Time scale to build	Approximately 30-42 months
Total cost	£0.013 per kWh
Precautions	Exclusion zone Omission of graphite core Corrosion resistant materials

Hydroelectric power
Renewable energies

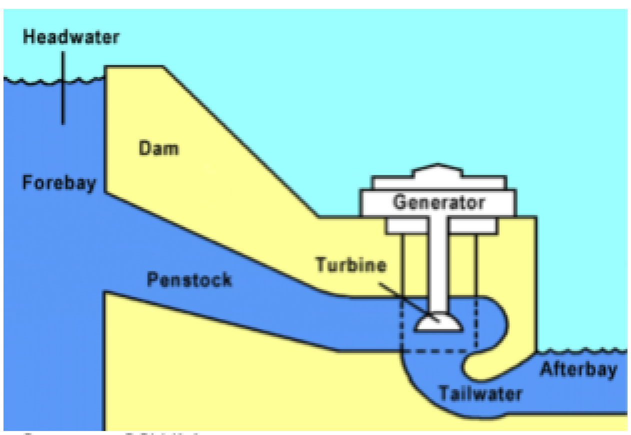
Utilizing outsourced power
20% of total power supply

Energy Production

There are two main methods of using the flow of water as a source of electricity, hydroelectric dams and run-of-river schemes. A new approach to hydropower in the next decade could see it producing up to 20-25% of our total energy requirement on our Solent City (based on figures for potential hydropower in the U.S.) [1]
Hydroelectric power will be crucial in supporting our Solent City because it is ideal for our coastal location and it can respond quickly to rapidly varying energy needs or system disturbances [2] – we would take advantage of this in the event of a high power demand.

How it works

To produce electricity, the water must be in motion. When the dam stores the water in the reservoir, it has gravitational potential energy. This is converted to kinetic energy when the water is released into the penstock. The kinetic energy from this is transmitted to the turbine. The generator uses the kinetic energy in the turbine to produce energy; when the rotor (in the generator) turns, it causes the electromagnets to move past the conductors mounted in the generator. This causes electricity to flow and a voltage to develop at the generator's output terminals.



Source: SSWM(9)

Hydroelectric Solution

It would be virtually impossible to implement a hydroelectric power source inside Solent City, because of the flat coastline and the reduced industrial area available. Since we require various heights of land, for the types of hydropower stations needed, not only would we need to construct our hydropower stations in the Meon Valley (our local drainage basin), but they would also need to be constructed in various locations, covering different rivers/tributaries. The main reason why we are not able to construct one large dam is because the rivers are too small and they do not have large waterfalls from which we could harness the energy. Despite this, there are locations where we can create medium-scale reservoirs and dams.

Pumped Storage

Pumped storage is a method of keeping water stored for peak power demands by pumping water that has already flowed down the penstock back up to a storage pool above the powerplant when demand for electricity is low, such the middle of the night. The water is then allowed to flow back through the turbine-generators when demand is high, so enough electricity is produced. For feasible plants in our solent city, we would highly reduce the risk of a power cut, but it cost about 23% more to generate power[5].

Costs of Energy & The Local Economy

Once up and running, the cost of producing the electricity itself by hydropower is very low (around $0.04-0.18 per kWh)[5]. Hence, the initial costs of construction make up the majority of the cost of hydroelectricity as an energy source.

These initial costs of dam/reservoir hydropower development include[5]:

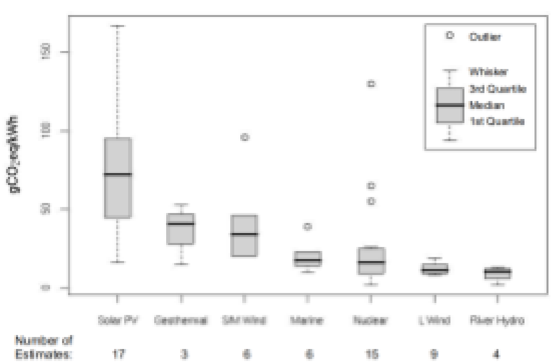
- Dam and reservoir construction
- Tunnelling and canal construction
- Powerhouse construction
- Site access infrastructure (durable roads)
- Grid connection
- Developer/owners costs (including planning, feasibility, permitting, etc.)

Obviously, the greater the power capacity of the power station, the greater the amount of energy we can utilise, however our hydropower stations are limited by the size of the rivers in the Meon Valley, so for one hydroelectric power station producing our required 25MW (per station), we estimate initial construction costs totalling £175-325 million[5,6], depending on the land's relief and the distance between the power station and our Solent City, etc.

Furthermore, we could make use of up to 4 hydroelectric power stations, across the Meon Valley, due to its river formations. Whether they'd be run-of-the-river power stations or hydroelectric dams, they could power 20-25% of our Solent City for an estimated £1 billion. Note that the cost of transmitting the power, building new substations/transformers and planning/permitting the stations are included in this estimate. Ideally, the city would begin construction in the next 3-5 years and develop the hydropower solutions over the next 20 years (spreading the cost thusly).

Carbon Emissions[4,8]

Fig 2. International Carbon Footprints for Low-Carbon Electricity



Source: UK Parliament(4)

All electrical energy solutions (using current technologies) incur some emitting of carbon dioxide emissions at some point in their life-span. When hydroelectric power stations are in operation, their emissions are very low, so the majority of the CO_2 is released during their construction.

Hydroelectric dam stations have a generally higher CO_2 (~10-30gCO_2eq/kWh)[8], than run-of-river schemes (<5gCO_2eq/kWh)[8], as they require large amounts of raw materials (steel and concrete) to construct the dam. It should be noted that run-of-the-river power stations have some of the lowest carbon footprints of all electricity generation technologies[8].

Solar Power
Centralised systems

Domestic Power
30% of total power supply

Introduction

What Solar energy is the process of harnessing light energy, using technologies such as solar panels, from the sun's rays and converting them into useful sources of electricity for us to use. The sun is a natural nuclear reactor that is renewable, and although the sun will die at some point in the future, this won’t be for millions of years to come. It provides a lot of energy on a 24hr basis making it extremely reliable and useful.

How solar panels work

Solar panels are usually used for electricity production, although some can be used as a heat source as well. Solar-powered photovoltaic (PV) panels convert the sun's rays into useful electricity by the photons from the sunlight ‘knocking’ electrons free from atoms and these atoms become charged, or ‘ions’. The ions are attracted to oppositely charged electrodes and create an electric current. Solar photovoltaic cells have a positive and negative thin layers of silicon under a thin sheet of glass, and this is where the ions are formed, with the negatively-charged free electrons attracted to one side of the silicon cell, and vice versa, which creates an electric current that can be collected and used.[2]

- Different sized solar panels contain more solar cells, and thus obtains a higher amount of sunlight energy. This is good for many countries e.g. Africa where there is lots of sun, very little climate change and most places are directly exposed to the sun.

- Even on smaller, commercial scales like houses in Britain, which also has an ever changing climate, the solar panel is extremely effective in producing electricity.

Domestic Solar Evaluation

Pros to Domestic Solar Energy:

- Reduces Electricity Bills for families and businesses through its Diverse Applications like heat and light production.[5]
- Low Maintenance Costs means less money involved and payback time is shorter.
- No Direct Pollution Or Noise Pollution which is good not only for the environment but also neighbours or surrounding areas as there's no noise pollution.
- Developing Technology Means More Efficiency and means solar energy can only improve tech wise, no there's no risk involved when buying panels.[5]
- They are 95% Recyclable which is good for the environment and may lessen production costs as materials reused[5]
- Most importantly, solar energy is in abundance, sustainable and reliable.

Cons of Domestic Solar Energy:

- Expensive initial cost, lump sum payment may not be easily done by families.
- Although it doesn't pollute, it indirectly causes pollution through using rare material like mercury, plus shipping and manufacturing all pollute.[5]
- Intermittent, although usually reliable they can be affected by weather,
- Energy storage is the main issue, the energy usually has to be used as it's made although, for example, Tesla are working on a solution for that.[6]
- Requires Space on a roof or land plot, this may cost money as well.

Solar Output/ Energy Requirements:

Typically, a 3kW to 4kW solar panel system will produce enough energy for a family sized home - the average family household consumption is 3,940kWh per annum, while a 2kW - 3kW solar panel system will typically provide for a smaller household. An average 4kW solar panel system will generate around 3,400kWh of free electricity a year, As for daily consumption, That's enough electricity to individually power:

- 4,857 hours of the washing machine
- 97,143 hours of the fridge
- 1,880 hours of boiling the kettle
- 1,417 hours of the oven

Costs of Solar:

The average household needs a solar panel to provide around 3kW. Solar panel cost will range from between £4000 and £6000[1] and will cover around 21 square meters of your roof. The more electricity your system can generate, the higher the initial installation cost, but the savings will also be higher in the long term[3,4]:

Typical System Size	Typical Annual Output	Estimated Cost	Est. First Year Return	Profit Over 20 Years
1kW	850 kWh	£3k-£4k	£130	£100
2kW	1,700 kWh	£4k-£5k	£222	£562
3kW	2,550 kWh	£5k-£6k	£316	£1,320
4kW	3,400 kWh	£6k-£8k	£404	£2,080

Commercial Solar:

Solar is a cost effective tool used by many people and families across the UK. but its not only useful for personal uses, it is also used by companies and commercial properties as a way to save money and help protect the environment in which they operate[7].

Average Costs

Size of Commercial System	Feed-in Tariff Rate Jan - March 2017	Feed-in Tariff Rate April - June 2017	Feed-in Tariff Rate July - Sept 2017	Feed-in Tariff Rate Oct - Dec 2017
10kW - 50kW	4.32	4.25	4.19	4.12
50kW - 250kW	1.99	1.94	1.89	1.84
250kW - 1 MW	1.65	1.59	1.55	1.50
1 MW+	0.52	0.47	0.42	0.37

Pros of Commercial Solar Energy:

The pros are near enough the same for commercial and personal solar, there are a few extra bonuses with a company choosing to use solar energy, with the main one being grants from the government. Some grants offer up to £5000, and others offer 15% of the installation cost.[7]

Cons of Commercial Solar Energy:

Solar energy for a company is a large investment and needs to be thoroughly thought through. For some companies these costs are like pocket change, but for other smaller, local businesses it an be hard to make the transition to solar, and although grants are in place it can still be a problem.

Solar Parks:

Solar parks are essentially a massive group of solar panels all lined up in rows in a very hot and dry climate. Many exist already, such as the Solar Star Park, Los Angeles County, California and the world's largest one, Longyangxia PV/Hydro power project, Gonghe, Qinghai in China[8]. These parks are a fantastic way to produce a lot of energy efficiently, consistently and successfully.

These parks however do require a lot of space, and obviously the bigger the park the larger the costs of installation and maintenance. “A simple rule of thumb is to take 100 sq ft for every 1 kW of solar panels. Extrapolating this, a 1 MW solar PV power plant should require about 100000 sq ft (about 2.5 acres, or 1 hectare).” [8]

Distribution
Transmission

Coping with peak demands
20% of total power supply

Overview

With an overall reliability of 99.999993%[1], the National Grid will be used to transmit our power over the city and surrounding areas. Our solent contains parts of Southampton, Gosport, Fareham and Portsmouth, in an estimated 92 square km in area so subsequently should use roughly 1.8-2.5%[4] of the National Grid's Electricity Transmission System (dependant on the distance between the city and our power sources).

For the sustainability of our solent city, we have 3 possible transmission solutions for the next 10 years:[3]

- High Voltage Alternating Current
- High Voltage Direct Current
- Superconducting Technology

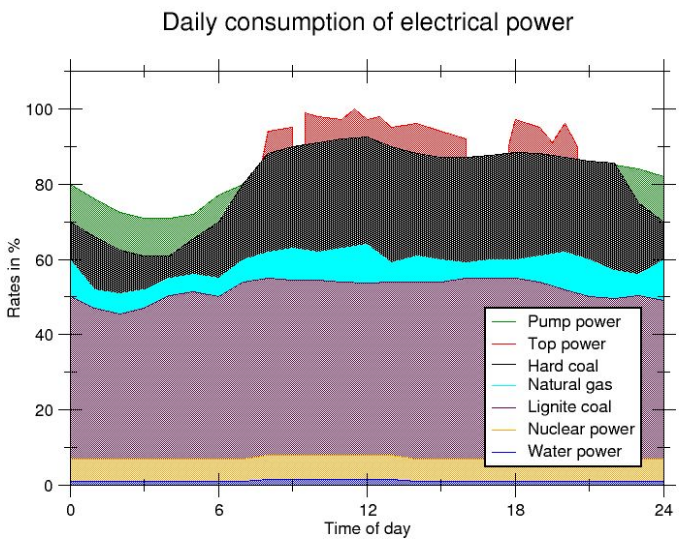
Our main transmission solution will be AC overhead lines, as they are rarely disrupted by weather in the UK and are far cheaper than underground lines.

How Electricity is Transmitted

The electricity comes out of the generating plant to some transformers, where the voltage is increased to a transmission voltage (132kV, 275kV, 400kV), so it can travel long distances on high-voltage, overhead transmission lines. The National Grid operates these lines, so in order to satisfy our city's demand and eliminate our dependence on fossil fuels, we would have to connect our new power sources to these lines. It's likely that we will have to increase the amount of high voltage transmission lines going in and out of Solent City, because of the remote locations of our proposed energy sources.

Next, the high-voltage electricity will go through transmission substations[6] (for industrial use) and local distribution substations (for domestic use). By passing through these substations, the electricity will become high-volume and suitable for short-distance transmission. Finally, distribution lines will connect homes and services to the National Grid, at 120-240V.

Peak Demand



According to our estimates, in one day, we would average about 11,685.8MWh of electricity used, across the whole solent city.

As seen in the 'Daily consumption of Electrical Power' graph[5], there is a significantly less energy demand in the early hours of the morning, and during this time, we would utilise the pumped storage of our hydroelectric power stations, to create more gravitational potential energy in the water, to be converted to kinetic energy during peak times, such as midday. Note, this graph shows Germany's electricity use and as such, we will consider a slightly lower energy demand for our solent city, as there will be less industrial energy consumption here, than there is currently in Germany.

Furthermore, by installing smart meters in homes across the UK, we can notify the public[8] when electricity is over-supplied and under-supplied, reducing electricity-use by 5-10% during peak times and increasing electricity use by 5% during over-supplied times[8] , in addition to reducing the overall cost to consumers.

Cost of Transmitting Carbon Neutral Power

Transmission costs in the UK will include:

- the price of raw materials needed for line and pylon construction
- the price of installing substations and transformers

Due to the increased distance between the city and our proposed electricity sources, the cost of transmitting the power will be increased, but still manageable. The most distant power source we'll employ will be hydroelectric, which will range from 10 km to 25 km away from Solent City, but also in rural areas (outside of protected national parks). For the transmission of high voltage AC (at 132kV and below), it will cost approximately £403,564 per mile (equivalent of £252,228 per km). Thus, the estimated cost of transmitting power to Solent City would be approximately £5,044,560.

Final Plan
Summary of Implementations

Final Costs and Time Scale
£5.2 billion and 16-20 years

Generation :

All energy in the city will be provided by:

- A 250 MW Molten Salt Nuclear Reactor,
- 4 Hydroelectric Dams,
- 500,000 3kW Pv panels

Capacity:

Prior to the implementation of energy saving technology across solent city our energy demand is estimated at 4,265,302 MWh per year and even after infrasture in the city is improved, although we hope our energy consumption will fall, we predict it will remain high due to the replacement of petrol powered transport with electric based technologies. Moreover, as technology progresses over the years it can only be assumed energy consumption will continue to rise in the future. Due to this we plan to generate over the energy requirement for the city to allow for technical advancements within the city. Our generation methods have the combined capacity to produce 4,536,000 MWh per year - ample to meet demand, supplied in the following proportions:

- Nuclear- 2,190,000 MWh per year
- Solar- 1,470,000 MWh per year
- Hydroelectric- 876,000 MWh per year

Excess energy will we sold to the UK government in order to help recuperate costs of construction and reduce the carbon footprint of Britain as a nation.

Implementation

Locations

To power solent city we rely on a range on local and imported energy sources. Our plants will be built locally and outside the city to make use of all natural resources available. Power for domestic consumption will be generated independently of the national grid to reduce energy lost in transmission and improve efficiency.

Local sources:

- Nuclear- 250 MW rector bases in Southampton
- Solar- a 3kW system installed on the roof of each individual property

Imported sources;

- Hydroelectric- 4 traditional/run-of-river dams based just outside city in Meon Valley

Construction costs

Although initial costs of construction for our project are high we have chosen systems with low running costs with the hope that fixing energy prices at current 13p kWh rates will satisfy consumers in conjunction with allowing use to repay government debt created during construction. Connecting our new technologies to the existing grid will save money on transmission and provide the least disruption to residents.

Technology	Construction costs	Generation costs
Nuclear Power Plant	£1.333 billion	£0.01 kWh
Hydroelectric Dams	£1 billion	£0.03 kWh
Pv Panels and Storage	£2.875 billion	N/A
Power Transmission	£5 million	N/A
Total	£5.2 billion	£0.02 average

It's worth noting that since the cost of Pv Panels is covered in domestic costs a grant of just £2.325 will be required to account for the Nuclear Plant, Hydroelectric dams and renovations to the grid.

Payback

Fixing prices at 13p per kWh ensures we profit 11p per kwh , £498,960,000 a year in total assuming all energy generated is used. This means we would require just over 4.5 years to repay the government £2.35 billion for the cost of installing our new technologies before we could look at re-adjusting electricity prices to benefit consumers.

Feasible Time Scale

- **Stage 1, 0-5 years**: Construction of Nuclear Reactor

  Initially we will demolish and relocate King George's dock in Southampton to make room for the construction of our Nuclear reactor since it will be the predominant source of power in the city and provides the most reliable source of energy. We estimate construction should take just 2.5years, however as the technology is new we have allowed extra time to account for any unforeseen issues.

- **Stage 2, 4-5 years:** Update national Grid

  In conjunction with installing our nuclear reactor we will make the necessary adjustments to the grid so Hydroelectric dams can be connected immediately after construction.

- **Stage 3, 5-7 years:** First Dam

  After we have completed the construction of our reactor we will begin the construction of our first dam costing around £250 million.

- **Stage 4, 7-10 years:** Pv Panel Installation

  Houses will now have sufficient modifications to make efficient use of solar power so we will begin the most expensive phase of renovations and instal domestic solar panels.

- **Stage 5, 10-16+ years:** Pv Panel Installation

  Finally, we will spend approximately 6 years constructing the remaining 3 dams to ensure all energy in the city is generated with minimal carbon emissions.

Transport
Demand

Land, Sea and Air Transport

Plan Overview

Requirements

As a highly developed city public transport, along with industrial and domestic vehicles are heavily relied upon in solent city, making it quintessential we ensure transport methods are as clean as possible in conjunction with encouraging the public to limit their use of petroleum vehicles in favour of public transport. Unfortunately, it will not be possible to eliminate the use of cars in the city as it will interfere with people's commutes however improving public transport, through monorails and bus rapid transit will reduce public dependency on polluting vehicles. Boris bikes should ensure leisure can be accessed in a more environmentally friendly manner and the use of electric ships will be implemented to improve carbon emissions of the dock regions.

Land	Air	Sea
Boris Bikes	No specific transport for air	Electric ships/ ferries
Bus rapid transit		
Monorails		
hydrogen/electric cars		

Current Carbon Emissions

The current CO_2 emission of the area in which the mega city will be placed is around 2518 kilo tonnes per year[1] a large proportion of this is produced by transport. By implementing these alternate carbon neutral transportation, we will be able to significantly reduce this value. Electric vehicles are the future of transportation because they do not produce CO_2 nor other polluting gases instead they release water like the hydrogen fuel cells. Additionally the power used by these methods will be sourced from renewable energy sources, which will help the mega city to be carbon neutral. Environmentally friendly cities such as copenhagen are already reliant on such schemes making them seem feasible to instal in the near future and ensuring they promise to meet the high demands of an urban development.

Land Transport
Boris Bikes

Domestic Transport
Reducing Requirement for Cars.

Overview

Boris bikes are just one name for this rental bike scheme that has been adopted in major cities like London, Paris and Copenhagen.

The Boris bike schemes consist of dockstations of rental bikes costing £2 for 24 hours [1] and Any additional time is pay by £2 every 30 minutes[1] . Once finished your journey Bikes can be left at any dock station around the city, London has 338 dock stations [1] .

Evaluation

Advantages of the scheme

As the bikes are purely powered by the rider no carbon emissions are produced. This could be a good way to counteract any carbon emissions from other areas of the project.

Additionally the money needed to kickstart the scheme could potentially be provided by sponsors e.g Barclays sponsors the Boris Bikes in London and in Paris a similar scheme is fully funded by one company

Disadvantages of the scheme

The disadvantages of this particular scheme are minimal and can be easily resolved. The main problem to overcome would be the cost of setting them up then maintenance needed for any of the bikes, however this could be dealt with by sponsorships (as I have said previously).

Costs

For a similar city to London, £140 million is needed to set up the 338 dock stations [1]. This averages out to £414,202 per dock station. The total population of London (2016) was 8,787,892[2] , compared to Portsmouth's population of 205,400[3] . This means we will only need a fifth of the amount of dockstations as our population is approximately a fifth of the population of London. The whole project would approximately cost £28,165,736.

Land Transport
Hydrogen Fuel Cell Cars

Domestic Transport

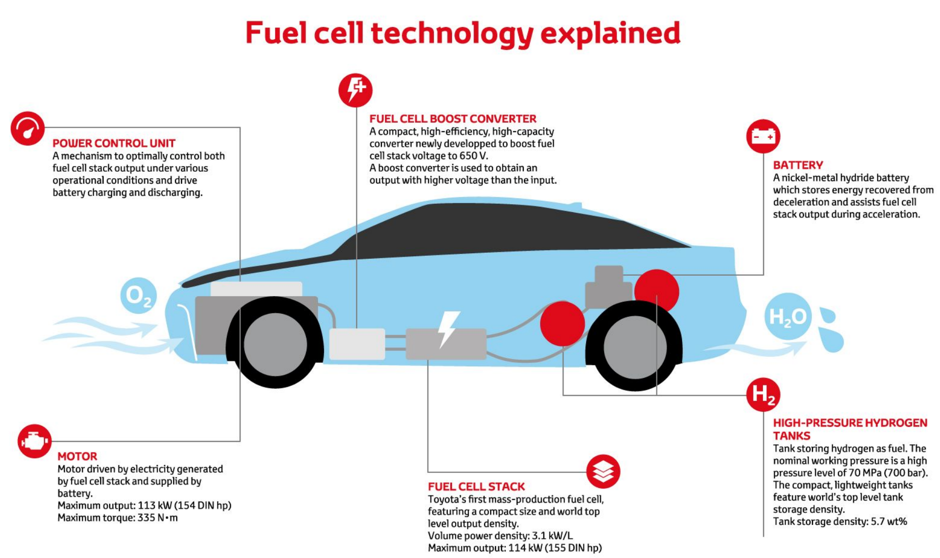
Reducing carbon Emissions of cars

Introduction

Hydrogen Fuel cell cars are a relatively new technology yet to be implemented on a large scale, however they provide a promising prospect for a replacement to petroleum or diesel fueled vehicles in the near future.

How they work

The vehicles run off of hydrogen gas stored in a compressed state in high pressure tanks located in the trunk or under the floor of the vehicle. The gas is passed through a fuel cell stack, which combines the pure hydrogen with atmospheric oxygen to generate an electric current that powers an electric motor connected to the wheels. Since the only emissions from the exhaust is residual water vapour, the cars are deemed as not only completely carbon neutral but equally as environmentally friendly as cycling. Similarly, to hybrid electric vehicles they utilize a battery pack, charged via a regenerative braking system. However, this battery is only required for acceleration so can be much smaller.[1]



Evaluation

Advantages

In addition to the obvious benefits of completely eradicating greenhouse gas emissions hydrogen fuel cell cars have a range of benefits including increased efficiency vs gas, diesel or even electric vehicles[3]. Moreover, fuel cells do not need conventional fuels such as oil or gas and can therefore reduce economic dependence on oil producing countries, creating greater energy security for the user nation[3]. The maintenance of fuel cells is simple since there are few moving parts in the system[3]. They also provide a far more convenient alternative to typical electric vehicles for consumers since they can be refilled with hydrogen gas in just 5 minutes eliminating lengthy charging times disrupting journeys.

Disadvantages

So this begs the question, why are we not already driving hydrogen fuel cell cars? Firstly as a new technology they are still incredibly expensive costing around £66,000 [3] with no option to purchase second hand. While, we would strongly advise consumers to purchase the cars it would be impossible to fund these cars for each driver in the region and not feasible to ask drivers to purchase their own. In addition the current price of hydrogen fuel makes cars expensive to run deterring people from considering them. It’s hoped that methods of carbon capture implemented in the city with reduce the price of hydrogen fuel as well a provide a renewable method of generating it decreasing the price in the future. Fueling stations are also far and few between so even if we installed them across the area, which we plan to in the next 30 or so years, long journeys would still provide logistical issues. Leasing with the government during the development of the city is hoped to provide an opportunity to ensure that fuel stations are made readily available for those who opt to purchase the cars.

Implementation

As mentioned previously, it will not be possible to eliminate the use of cars in the city as it will interfere with people's commutes and consumer rights however improving public transport, through monorails and bus rapid transit will reduce public dependency on polluting vehicles. Instead research will be funded into the development of fuel cell cars to hopefully see that they become a popular choice in the near future. Of course they will be highly promoted and system like priority parking will be implemented to ensure that the public see the benefits to purchasing them. During the development of infrastructure in the city more hydrogen refueling stations will be built focusing on more commercial areas like West Quay and Portsmouth city center. Tax will also be increased on petrol vehicles and within 15 years the sale of any car that does not currently meet criteria to be exempt from road tax will be prohibited.

Land Transport
Bus Rapid Transit

Public Transport
Reducing Carbon Output of Public Transport

How they work

Public transport plays a significant part in transporting people around Britain. Over 5.04 billion local bus passenger journeys were made in 2015/2016[1].

Bus Rapid Transit is an public transport system which uses segregated lanes for the buses with junctions along the way. The buses operate with electric or hybrid engines. The engines of the buses are hybrid electric meaning that they keep the energy stored within the vehicle. The engine combines a conventional engines propulsion system with an electric propulsion system [2].

Carbon Emissions

Over the years the consumption of CO2 has increased dramatically ; 514.4 million tonnes of CO2 equivalent (MtCO2e) total net domestic emission from all sources and 23% (118.312 million tonnes) greenhouse gas emission were from transport. However, electric hybrid engines reduces the emission of CO2 and makes the engines more environmentally friendly. [7] It reduces the emission of carbon dioxide by nearly 250,000 tonnes equivalent per year[4].

Capacity

Each bus has the capacity to carry 50-200 passengers and can operate at the speed of 27-48 km/h [1]. Statistically, 7% of the population of England used public transport [9], therefore if each bus can carry the maximum of 200 passengers, in the population of Solent City (2 million) 140,000 people would use public transport. Meaning, we would require approximately 700 buses. It is estimated that BRT costs less than £7 million per kilometre[12].

The Bus Rapid Transit system is used quite well in populated countries such as China, India and Pakistan. In these countries, the buses carry around approximately 150,000 passengers daily and the system can extend to over 70 km [1] .

[BRT in Delhi, India] [10]

Benefits

Reduced Commute Time

The dedicated lanes which separated the buses from the passing traffic allowing them to reach their destination/junction much quicker, this makes the Bus Rapid Transit system more time effective [1].

Safety

A quite significant problem with buses and cars is that a lot of accidents occur which risks an ordinary civilians life, however using the bus rapid transit the risk of car/traffic accidents are reduced dramatically. The risk of traffic accidents has been reduced to 30-40% after implementation of this specific bus system [2]. This is due to the fact that the buses travel in separate lanes from the remaining traffic and can travel with their own individual speed allowing them to be more safer and more time-effective.

Reduced Pollution

Being more environmentally friendly is the most substantial for Solent City, hybrid electric buses have specific engines which produce renewable energy therefore they reduces air pollution and the emission of greenhouse gas [1] [2].

Efficiency

The Bus Rapid Transit system is more reliable and predictable. The bus fare are either prepaid or are electronic passes, this increases conveniences and is more time-effective as less time is wasted on boarding and paying for the passes as you enter[1].

This type of transport system is quite modern and reliable.

Land Transport
Monorails

Public Transport

Reducing Carbon Emissions of Public Transport

Introduction

Public transport like busses and taxis are very useful but they still emit CO_2 and harm the environment. The monorail system can reduce this affect quite significantly as it can be run electrically by solar panels fitted on top of the carriage which means that it will not contribute to CO_2 emissions directly.

How They Work

A monorail sits on a single solid beam/ rail that is elevated, the carriages have conductive shoes to transmit current to the train, the rubber wheels are connect the carriage to the rail which allows them to travel along the beam. Another wheel is used to straddle electricity giving the monorail power to move.

Advantages

They require a small amount of space, they are very quiet, modern monorails look very attractive, they do not block the sky majorly, reduce CO_2 emissions, very safe as it is physically not capable of derailing unless there is some sort of major malfunction.

Disadvantages

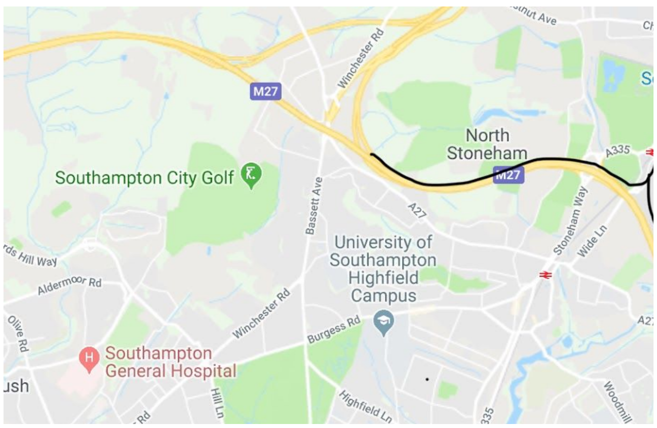
In emergency situations passengers are not able to exit the carriages because of the height at which the monorails travel, and will have to wait for a rescue train or cherry picker to rescue them. It is quite expensive to add extra tracks because of the linear nature of the track.

Implementation

Cost

The pricing of existing monorails all over the world ranges from £10.6-£62.7 million/km, [2] which is expensive, the price varies from the type of monorail as well as the number of miles. The cheapest type is normally the Hitachi and the most expensive being the Bombardier MVI. Power consumption of current monorails are around 137 KWH is the per train per hour[3].

Location



The diagram shows where the main section of the monorail system will be placed, the system will cover a distance of around 3 miles (4.8 km). Total cost for this would be £51.3- £300 million depending on the type of system. To keep costs manageable, while not compromising quality we would be looking at installing a £70 million system.

Map solent city region [4]

Sea Transport
Electric Ships

Industrial Transport

Alternative Fuel Sources for Ships.

Introduction

Ships, ferries and other water transports are vital in the movement of good and connecting the world by water. Ships are seen to be the smallest emitters of CO_2 but they can damage the environment because they emit tonnes of CO_2 and many scenarios of water pollution through oil leakages that have killed many aquatic wildlife.

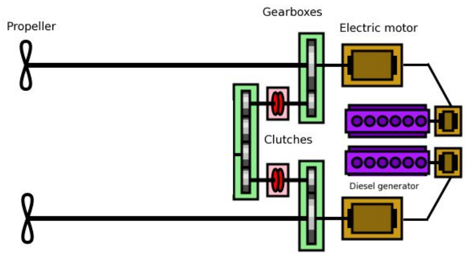
Standard ships run on diesel oil, larger cargo ships tend to use Heavy Fuel Oil (HFO) , High/ Low Sulfur Fuel Oil (H/ LSFO). They can burn more than 130 tons of fuel a day when travelling at a constant speed[1]. A modern ship (freight) can emit 10-40g CO_2 per metric ton of freight and per km[2].

To reduce the emission of CO_2, use of fossil fuels and damage to aquatic ecosystems, an alternative method will be electric ships that run on a battery instead of diesel. They are still in development but are coming near to production.

Examples

Countries like China have already launched electrical cargo ships constructed by Guangzhou Shipyard International Company Ltd. After being charged for 2 hours the ship is able to travel 50 miles (80 km). It is powered by a 2400 kWh battery, and can travel up to 8 mph (12.4 km h).[3] Another zero emission electric ship is planned for operation in 2018 by a Norwegian chemical company Yara International ASA.

How it works?



The ship will use an electric motor to propel itself, the electricity can be generated in many ways such as a wind turbine or solar panels on the deck, or it could use a diesel generator but that will increase emission of CO_2. Another way is that the ship can be charged at docks by national grid.

[4]

Advantages

- The system for electrical propulsion will require less space than the conventional method.
- Severe stresses like torsional and vibrations are restricted as there is no direct connection between prime mover and propeller shaft.
- Running cost of the ship will be cheaper due to reduction in fuel and emission
- It can be used in all types of maritime vehicles

Concerns

The electric propulsion costs slightly more to implement compare to the conventional system. There is no exact value but can be £75 million- £105 million to build a new ship and around £10 million to replace conventional systems with electric systems.[6]

Implementation

The electric motor and propulsion will be implemented in ferries that travel by Portsmouth regularly, new ships and ferries that are manufactured will be fitted with electric propulsion system. These will replace the older ferries with the conventional system that are currently being used. Large freighters owned by foreign companies will be asked to fit their ships with a hybrid system, because it will not be convenient for them to quickly add a new system as it will be expensive for them. The hybrid system uses a diesel generator to power the motor and can run on a battery, as the ship comes into the city the ship will be switched to electric, this will keep CO_2 emission in the city low. Hybrid systems used currently can save fuel, in the ships lifetime it could save up to around $250 million [7]. The use of this electric and hybrid system will significantly reduce CO_2 emissions in the city.

Air Transport
Restriction of Landing space

Domestic Transport
Discourage Unnecessary use of Air Transport

Demand
The city does not have any large international airports, apart from Solent Airport which is an airfield used for private uses, flying lessons and light aircrafts. If you have a private jet or helicopter this will be the only site for you to land within the city. As a result of this the city will have to use the nearest airport which is Southampton airport for international and domestic flights. Money can be spent on Solent airport so that it is able to handle small domestic flight and more aircrafts, which will allow direct access into the city by air.

Carbon Emissions
We will not be using a specific transport for air because the city does not have enough space for this (as explained above), we will be using the current aircrafts in production which will land in airfields/airports (Southampton airport) outside the city. The carbon emission from air ambulances and other small aircrafts are significantly small compared to other methods of transport in the air and in the world, they produce only 2% of all aviation emissions and only 0.04% of all man made carbon emitters in the world[1]. As a result of this small aircrafts and helicopters travelling over our air space or landing in the airfield will not have a significant impact on our carbon neutrality.

Future plans
As technology is developing it does give the chance to use big airlines that can run on renewable energy, as this is not completely possible now, it can be implemented in the future.

Final Plan
Summary of Implementations

Final Costs and Time Scale
£34 billion and 15 years

Technologies

We have chosen to implement strategies focusing heavily on increasing use of public transport as it's easier to control than domestic cars. Road tax will be increased and a poll tax will be introduced to polluting vehicles entering the city. Over the next 10 years we aim to phase out the use of high emission cars by introducing restrictions to maximum CO2 emissions tested in annual MOT. Hydrogen fuel cell cars will be encouraged and it's hoped that as the technology develops prices will decrease making them a feasible option. Industrial transport will also be updated particularly focusing on reducing carbon emissions of docks. The table below shows what technologies we wish to implement an their cost as well as CO2 emissions.

Technology	Cost	Carbon emission per year
Boris Bikes	£28,165,736	0
Bus rapid transit	£7 million	5000 tonnes
hydrogen/electric cars	£33 billion (1 car per house-500000)	0
Monorails	£300 million	0
Electric Ships	£1.05 billion (10 ship)	0
Total	£34.38516574 billion	5000 tonnes

Implementation

- **<u>Stage 1, 1-3 years- Boris Bikes:</u>**
  The Boris bikes will be implemented first because this will be the easiest to do as there is not much work with to be done with it, the whole project would approximately cost £28,165,736 and it won't take long to implement. People will be encouraged to commute to work with the bikes within the city as this will reduce congestion on roads and help people to have a healthy active lifestyle. Higher car tax will also be introduced to promote the scheme.

- **<u>Stage 2, 3-5 years- Bus Rapid Transit and Hydrogen fuel cell cars :</u>**
  The bus rapid transit and hydrogen fuel cell will be done next to begin reducing CO_2 emission in the city. We will need to encourage residents living in the mega city to trade in their old diesel/petrol car in for a hydrogen fuel cell like the Toyota Mirai which costs £66,000. The sale of Cars that do not meet current standards to be exempt from road tax will be prohibited.

- **<u>Stage 3, 5-15 years- Monorails and Electric Ships</u>**
  final stage of implementation will be the electric propulsion for ships and the monorail because these will be the most expensive method to implement. The monorail will cost roughly £175 million to build and it will take around more than 2 years for it to be completely established, the power consumption of these trains will be 137 KWH is the per train per hour, if it is necessary in the future the system can be made larger to include more of the city. To make new electric ships and ferries it will roughly cost £100 million, current ferry companies will be asked to replace their conventional system with electric systems which can cost £10 million. Shipping companies that use the waters around the city will be asked to add and electric system that can be operational when they travel into the city. As of now no alternate air transport will be used, but as technology develops we would like to implement zero emission aircrafts that can fly over the mega city air space. The small aircrafts and helicopters that will be able to use the current air space will not contribute large amounts of CO_2 because it is only 2% of all aviation emissions and aircrafts won't be constantly passing over every second so it will still help the city to be carbon neutral.

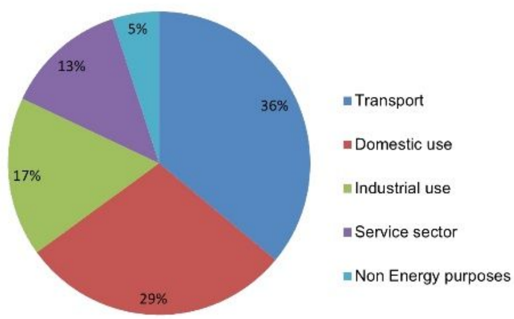
Domestic

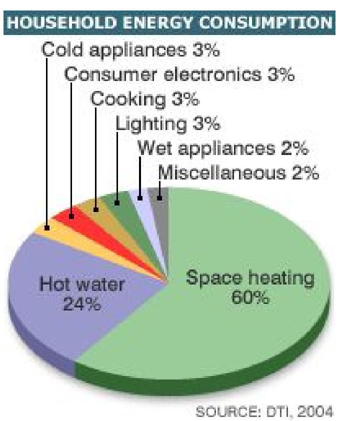
Public Consumption

Reducing Energy Consumption in the Home

Plan Overview

Despite average electricity consumption having fallen in recent years[1] and tighter construction regulations leading to an increase in more energy efficient building standards[2], the domestic sector still accounts for over 30% of the UK's energy consumption[3] using approximately 700 tWh per year[4].This has an extremely detrimental effect of the environment contributing to over 13% of the Uk's 381.1 million tonne carbon footprint[5]. Reducing this is vital to ensuring carbon neutrality in Solent city. Currently each terraced house based on pre 2010 building regulations with an average size of 82.6m^2 [6] occupied by 4 residents would consume a staggering 32,720 kWh[1,7] of energy a year, with a vast majority (around 60%[8]) consumed for space heating. That's 16.4 tWh for the entire city. Although passive housing requiring no energy to heat and producing electricity from renewable sources does exist[9], this would be impossible to implement across the city and thus our aim is to reduce our energy consumption by a least 70%, creating carbon neutrality by supplying this energy via clean sources of energy used for the national grid. It's to be noted that calculation of savings and costs throughout the report relate to the current energy expenditure of a home and thus do not directly correlate to the costs in the final implementation category, which are based solely off of the energy requirements for the houses designed.





Energy consumption of uk by sector [3]

Infrastructure
Carbon Neutral Housing

Achieving Houses with Zero Net Carbon Emissions
500,000 Homes

Layout

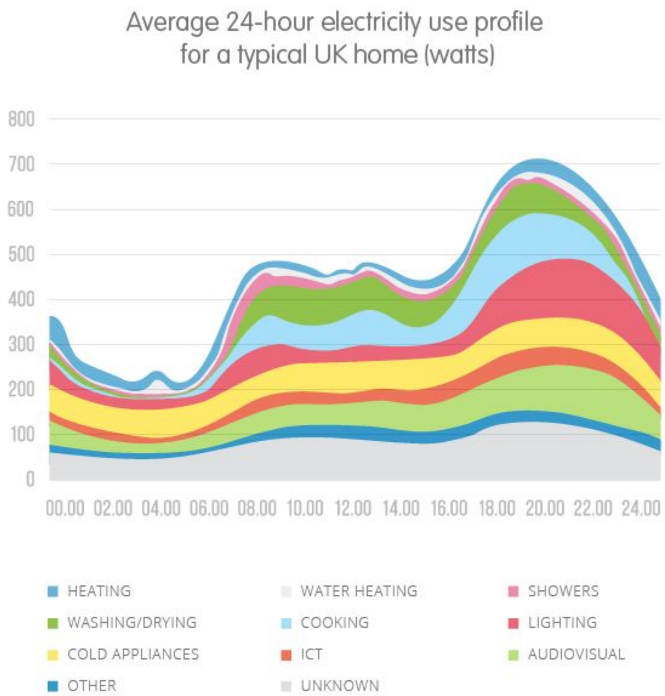
Floor plan

We have based our housing solutions off of a generic two-story terraced house since this is the most common style of housing in the area. Preferably all new houses built will be terraced since this not only saves space allowing for more areas of vegetation to extract CO_2 from the atmosphere but provides extra insulation reducing energy required for space heating since there are less external walls. Our standard house measures 82.6 square foot split between 2 stories with 2 bathrooms, 3 bedrooms, a kitchen-dining space, 2 hallways and a living room with a roof angle of 30 to optimise solar gain[10]. Two doors measuring 1.7 m squared provide access to outside space and the total area of windows measures 5.5m squared divided into 5 separate units.

Estates

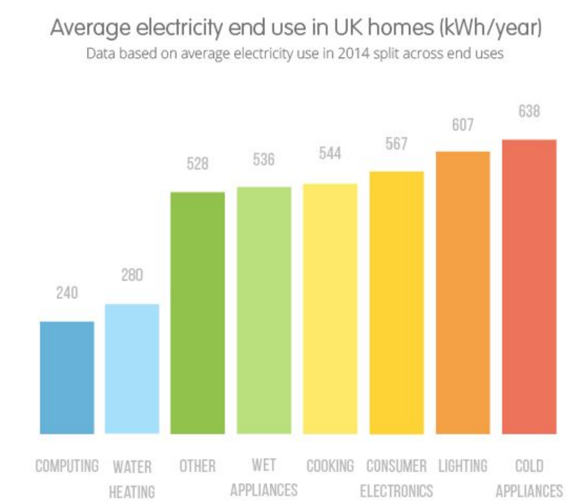
The efficiency of individual properties is not the only factor to consider when constructing energy efficient housing estates, the relative placement of domestic buildings and commercial ones is also quintessential in maximising the potential carbon reduction in a city. Zoning is a popular technique used by many eco estates to enhance the energy efficiency of their buildings[11]. Spaces for employment and community use are placed in the shadow zones of south facing terraced housing to not only increase the efficiency of domestic solar panels and reduce heat loss from housing in the winter but avoid the tendency for summer overheating of workspaces and the need for fan driven ventilation or air conditioning[11]. Mixed use developments combining industrial, domestic and leisure facilities not only create a sense of community but discourages the use of transportation to further reduce an estates carbon footprint. Integrating sports pitches and allotments encourages environmentally sustainable hobbies to decrease electricity consumption in the entertainment sector and the accumulation of greenhouse gases from importing food. Through uniting communities it's hoped it will be easier to raise public awareness of environmental issues and promote a greener lifestyle.

Electricity



Uk electricity use times [19]

A typical Uk uses 3940 kWh[1] of electricity a year excluding that used for space heating, about 20% higher than the global average for electrified homes[1]. Due to an increase in awareness of environmental issues associated with electricity generation this has fallen, however still exceeds the european average of 3600kWh[1]. Demand for electricity use peaks at around 6-7pm[1] when a majority of people return home from work, but it does remain above 250W[1] even at night suggesting a large percentage of energy is consumed by products left on standby and as a nation we still need education about how to conserve energy to lead a sustainable lifestyle. A majority of this electricity is used for cold appliances[1], unsurprising as fridges require a constant supply of energy to function. Lighting uses the second highest amount of energy at around 591 kWh per annum[1]. With the recent reduction in the cost of energy saving bulbs its felt this can be easily and cheaply rectified in the near future. Consumer electronics and cooking follow closely behind driven up by use of electricity to provide entertainment in modern lifestyles. Reducing this will require emphasis on more sustainable hobbies such as sports to improve not only solent cities carbon footprint but the overall health of citizens as well. The rise of laptops and tablets has lead to a reduction in energy required for computing as they require minimal charging to operate and are not connected to the mains like desktop computers.

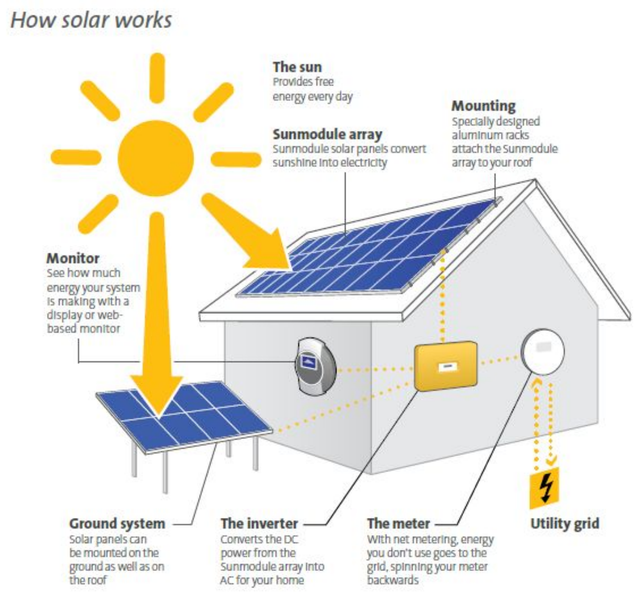


Uk electricity use breakdown[19]

Generation

PV Solar Panels

Eliminating all net carbon emissions from solent city, will require the city to severely reduce its dependency on the national grid, instead relying on renewable energy sources to meet domestic need for electricity in conjunction to cutting overall consumption as to avoid extortionate costs from implementing multiple carbon capture methods. Even with the UK's less than desirable weather conditions the reliability of solar panels make them a far more effective choice for energy generation than other renewables like wind power[13]. Solent cities location rules out the possibility of geothermal power, because of a lack of volcanic activity underground and hydroelectric energy generation would not be possible in inner cities miles from a natural water source. Although the use of solar panels in the uk is often a controversial topic doe to questions over there effectiveness in shadier climates, cells don't need direct sunlight to work – they can still generate some electricity on a cloudy day thus are a practical option for solent city, particularly as we have limited space. Solar panels consist of PV cells, that are made from layers of semiconducting material, usually silicon[14]. When light shines on the cell it creates an electric field across the layers. The stronger the sunshine, the more electricity is produced. Groups of cells are mounted together in panels typically mounted on roofs when used domestically. Solar PV needs little maintenance – panels just need to be relatively clean and not overshadowed by trees to operate. In the UK panels that are tilted at 15° or more have the benefit of being cleaned by rainfall to ensure optimal performance[14]. The orientation of panels is key to ensuring they operate a maximum efficiency throughout the year. Where possible panels should face south and they should be tilted at specific angles depending on season to absorb maximum sunlight.In portsmouth this is 16 degrees from vertical in winter ,39 degrees in spring and autumn and 62 degrees in summer [15]. As solar panels are particularly expensive it's important to determine a balance between the cost of cells and their capacity to produce electricity. In the uk the consumption of household electricity fell to just 3,940 kwh a year[1] and due to increased awareness of environmental issues is unlikely to rise. A 3kwh system has the capacity to produce 2,940 kwh [16] of electricity per year - 74% of the electricity required by a home and costs around £4000 to instal[17]. They are fairly small taking up just 19.8m squared of space[17]. Per £1 spent they produce 0.73 kwh energy in



How solar panels work [73]

the first year. The average sized System installed in the uk is a 4kW system costing £6000[17] and producing upto 3904 kwh electricity per year[16] - enough to completely power an entire household. For each pound spent in the first year they produce 0.65 kwh of electricity. While this cost does amount to significantly more, installing larger panels will mean that homeowners receive a higher feed-in- tariff payment from the government. For each kwh generated they earn 3.93p from the generation tariff and 5.03 p from the export tariff [16]equating to an annual payment of £324[16]. For a 3kw system of the same size a house will receive just £261[16]. On average a typical electricity bill costs £1,153 [18] a year. This means the payback time of a kwh system is nearly 17 years and a 3kwh system just 14. Installing 4 kwh panels to every home in solent city would amount to a total expenditure of £3 million, however it would decrease the demand for electricity to just 18 million kwh- negligible compared with the current 2 billion kWh, reducing CO2 output of each house by 1372 kg per year[19], 686000 tonnes across the city. Installing 3 kWh panels would result in a reducing of CO2 by 1033 kg per household or 516500 tonnes for they city[19]. Although installing 4 kWh panels would result in a far greater reduction in the cities carbon footprint the start up costs prevent it being a possibility, hence we have opted for a 3kwh system per household with the intention of reducing energy consumption through the use of cheaper technologies.

Storage

As solar panels generate electricity using energy produced by the sun they are unable to operate at maximum efficiency on cloudy days or at night time, subsequently to maximise the benefits of solar power it's important to install a solar battery to store excess energy for use when the performance of the panels are compromised[21]. Solar batteries provide a constant source of renewable electricity allowing houses to reduce their dependency on the national grid. The storage capacity of systems range from 1 Kwh to 14kwh[21]. As we installed 3kwh PV panels it seems sensible to combine them with a 3kwh storage system to ensure 100% of the energy generated is used. A 3.3 kWh solax battery system costs upwards of £1,750[20], however since solar batteries typically reduce energy wastage by 30% it's well worth the cost[21].

Appliances

TV

With the widespread popularity of gaming consoles and televisions, entertainment accounts for 14% of a households annual energy consumption[12], using 567 kWh of electricity a year[12]. Operating a typical plasma tv requires up to 658 kWh a year[12], while a standard led consumes up to 200 kwh[12]. Due to this TVs are the single largest contributor to the energy used for entertainment[12]. By switching a 32 inch LCD TV with an equivalent sized LED one homeowners would save 149 kwh of electricity a year saving £20.50 per year and £50 off capital costs since LED TVs are often cheaper to purchase[22].

Fridge

Cold appliances like fridges are the largest contributor to household energy consumption accounting for 638 kWh a year of energy used by a home per year[12]. Since fridges require a constant supply of electricity to operate this is no surprise, however improvements in energy efficiency mean fridges can now by manufacturers with A++ efficiency ratings. A standard upright fridge freezer uses 427 kwh a year[12]. Switching to an A+ fridge freezer would require just 200kWh[12] and encouraging households to pack their fridges neatly would ensure an average of just 1 per household as opposed to the typical 1.7 average[12]. A new energy efficient fridge would cost around £500[23] so they are fairly expensive however this is only £300 more than a standard fridge freezer and would reduce electricity bills by as much a £60 a year[23].

White goods

Most household complete approximately 238 washing cycles per year amounting to 166 kWh of energy[12], combined with the average 393 kWh[12] used by tumble dryers to this adds to 559 kWh electricity just for laundry- if there ever was an excuse to just kick your dirty clothes under your bed this would be it. Dual washer-dryers are a much more efficient enct alternative using just 243 kWh[12] a year to complete an equal volume of washing. An A rated washer dryer would cost just £300[22] and save 316 kWh of electricity. Since replacing a washing machine and a tumble dryer individually would cost at least £360[22] for inefficient models, with consequently high running costs, this would result in both an energy and cash saving.

Dishwashers are present in an average of 45% of houses[12] contributing an annualised average of 294 kWh[12] to a houses energy consumption. Simply by banning dishwashers and encouraging people to wash up by hand we would save 294 kWh of energy per household along with £42 per year in running costs.

Cooking

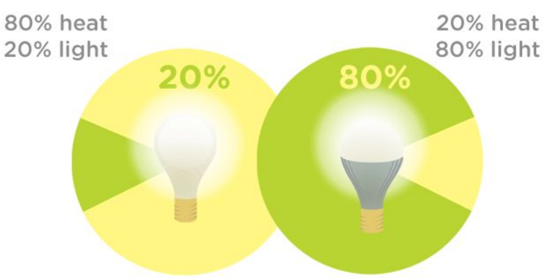
The combined consumption of electricity for ovens, hobs, cookers, deep fat fryers, microwaves, toasters and kettles amounts to a staggering average of 460 kWh of electricity a year costing house holds £66[12]. Although this is difficult to reduce encouraging people to cook in larger groups could see a large reduction in the average use of electricity for cooking per person since the relative efficiency of cooking for multiple people is higher than that of a single person[12]. By promoting social gatherings around mealtimes could reduce the kWh of energy required for each person by as much as 78%.

Lighting

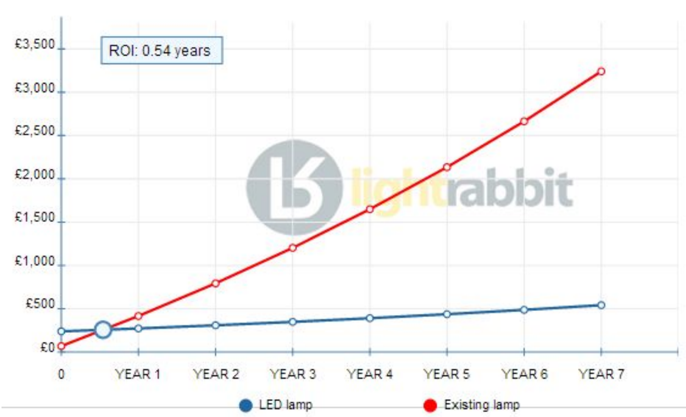
Traditionally lighting is one of the highest sources of domestic energy consumption- currently the Average uk home uses 15% of it's 3940 Kwh a year energy consumption on lighting, that's a staggering 591 kWh per year for each household[12]. This puts the consumption of energy for domestic lighting at approximately 272850000 KWh per year for the whole of solent city (based on average 3 bed home shared between 4 residents).

LED bulbs

We have opted to use solely Led bulbs as light sources in our domestic housing to directly reduce energy consumption, without impacting the lives of residents. Compared to standard incandescent lighting Led bulbs use 90% less energy since they generate light through the use of semiconductors, which emit light when an electric current is passed through as opposed to wire filaments which generate a vast amount of thermal energy[24]. This drastically reduces the energy wasted as heat since 95% energy is converted to electricity compared to just 5% in a standard bulb[25]. Typical Led lights also require less energy to run, a standard 84 watt fluorescent bulb can be replaced by a 36 watt Led[26] not only reducing energy use but the cost to homeowners as well. Whatsmore, LEDs have a better quality of light distribution and focus light in one direction as opposed to other types of lighting which waste energy by emitting light in all directions[25], often illuminating areas where light isn't required . This means that less LED lights are needed to achieve the same level of brightness given off by fluorescence and incandescent lights. Fewer lights will reduce energy consumption and subsequently carbon footprint. Less manufacturing will also be required Since Led bulbs last 6 times longer[27] again reducing cost to consumers as well as carbon emissions in industry. On average a household contains 34 lights[12], including lamps. While, Replacing each of these with an LED bulb could cost up to £ 170 per household[27]. The longer life span and increased efficiency of Led bulbs result in a monthly saving of £26.14[12] and a payback time of just 0.5 years. Since a standard Led bulb uses just 6 KWH a year energy[1] consumption for domestic lighting will be reduced to just 204 kWH, a 63% energy saving and an incredible reduction in co2



LED efficiency [74]



LED payback time [75]

emissions of 185.64Kg a month. Although replacing every lamp in every household will total approximately £85 million with such as short payback time and substantial reduction in energy usage, it's quintessential to ensure a carbon neutral city. With an average saving of £143 per household in the first year, around £71.9 million would be recuperated just 12 months after installment, and by 2025 there would be an average saving of £1.35 billion making Led bulbs well worth the investment.

Tubular Daylight devices

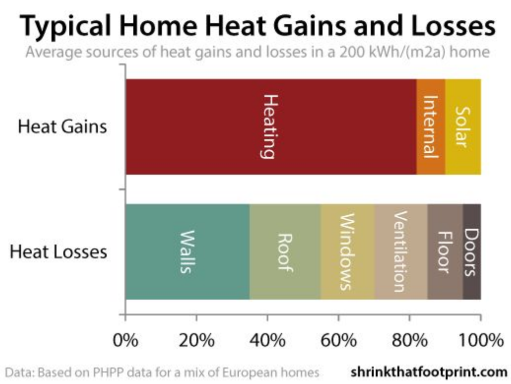
Solatube Daylighting Systems gather natural light at roof level then transfer it via highly reflective tubing to a ceiling fitting which diffuses natural light into the room below, reducing the need for artificial lighting in the home[28]. They require no mechanical parts and compared to other systems are relatively inexpensive yet efficient at lighting centralized area of terraced homes, which otherwise receive little daylight[28]. Tests by Durham University have found that up to 12 times the equivalent light of a 100-watt light bulb can be achieved with a sunpipe using three metres of flexible reflective tubing and even cheaper models are a approximately[29] . The sunpipe will perform best if facing due south and if the diffuser is directly below the collector[29]. Flexible sun pipes cost as little as little as £332.50 for an 82 inch base kit plus 3 extension[31] and are cable to lighting 3 bedroom or bathrooms[30]. This would reduce the number of lights required by each home by approximately 10 reducing the start up cost of using Led bulbs by £50 (30%) and the overall energy consumption for lighting per house by another 30% to just 144 kWh per year.

Daylight sensors

Home will be fitted with daylight sensors in communal areas, both upstairs and downstairs to reduce unnecessary energy consumption. sensors will be placed in the kitchen, bathrooms and living room to to turn off unnecessary lights reducing waste energy. An LED multi driver costs £40 [32] and each dimmer approximately £16.00 [32] meaning a total cost of £88 per home. While this is more expensive than simply encouraging people to turn off their lighting of their own accord, it is far more reliable and efficient in reducing waste energy Households with an energy consumption for lighting of 25% or more below the current national average will have the option of not installing sensors in an effort to encourage consumers to save money by making conscious decisions about their use of lighting. These would only be suggested to homeowners with energy consumption for lighting over the national average after a mandatory smart meter had failed to reduce there lighting consumption based on circumstances, for example extremely large families or houses with residents with impaired vision may be exempt.

Heating solutions

Insulation

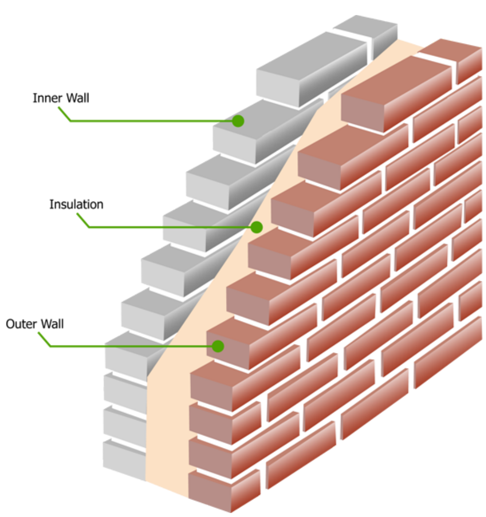


Typical heat loss of uk home [76]

Typically the average uninsulated uk home uses 300 kWh per m2 per annum in order to heat their homes[33], equating to 24,780kwh for an average 86.2m2 building. Utilizing building materials with a low thermal conductivity is imperative in reducing domestic energy consumption by minimising heat energy lost to surroundings and subsequently overall consumer consumption.

Cavity wall insulation

Houses in the uk built between 1930 and 1995 commonly comprise of unfilled cavity walls[34], with u values of between 2.0 W/m2K and 0.6 W/m2K[38] depending on the era they were built meaning they are incredibly inefficient in retaining thermal energy generated by heating systems. Current building regulations require all new builds to have walls with u values of 0.3 or belew[38]. This can easily be achieved with installation of 150mm of wool insulation, 100mm of celotex, which typically reduce u-value of a house to just 0.2 W/m2k[36] . Mineral wool insulation often consists of granulated spun glass or rock wall treated with a water repellent to prevent damp when installed[37]. It's a far cheaper choice than celotex and can be manufactured from waste or recycled materials to reduce co2 emissions generated in production[36]. The average cost of installing cavity wall insulation in a 3 bed terraced house, the style of housing prominandley used in solent city is £370[36], however with a typical reduction in heat loss of 60%[38] it could save homeowner £95 per year giving it a payback time of just 4 years[36]. Around 125 kwh of heat energy per m^2 is lost from walls for every m^2, meaning approximately 10,300 kwh of energy are lost every year[38]. By reducing this heat loss by 60% we are reducing the average energy loss per house by 6,180kwh bringing the average for heat to just 4120 kwh and total consumption per house for heating to 18,600 kwh.



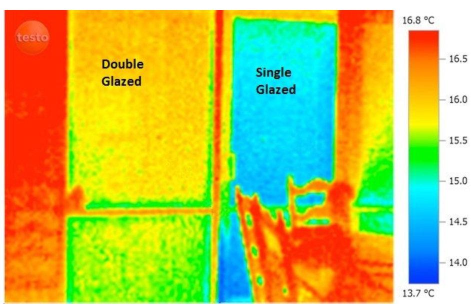
Cavity wall insulation [77]

Internal wall insulation

To further reduce energy loss through walls of a home internal wall insulation may be fitted in many cases directly to the internal wall, although more expensive than cavity wall insulation it is still far more cost effective in than external wall insulation and could greatly reduce the energy lost from a home. While the installation cost on internal wall insulation is high, it would represent a significant, 40% reduction in energy used to heat a home[38]. With our current energy consumption for heating at 4120 kwh this would result in a saving of 1648 kwh, which would mean the average house would waste just 2472 kwh through walls per annum just 24% of its original wastage. Although there are obvious benefits to installing internal wall insulation it does have complications and generally decrease the square foot print of a room. Its high cost means it would not be feasible to install throughout solent city however, it would be highly recommended to homeowners and grants would be provided if cavity wall insulation was not feasible. Schemes to encourage homeowners to reduce their energy consumption reducing energy prices for the most efficient homes will promote internal wall insulation in order to encourage homeowners to purchase it themselves.

Windows

In the Uk an average of just 62% of homes are double glazed[39], with the remaining 48% still relying on efficient, single glazing. With an average of 10-20% of a uk homes heat lost through windows[33] upgrading these to a higher standard of insulation is paramount in reducing solent cities energy consumption. Due to an incredibly high u value of 5 poor quality singley glazed windows[4], based on the average terraced house with 5.5m squared of windows could lose as much as 1317 kwh of heat through its windows in january alone. In fact with portsmouths dismal average temperatures this standard single glazed house could lose a staggering 8154 kwh of energy a year just through its windows. Fortunately, there is an obvious solution- double glazing. Double glazing consists of to separate panels of glass separated by a 5-12mm gap between panes, filled with air, designed to utilize air's low thermal conductivity minimising transfer of heat energy by conduction[41]. Not only are they effective in keeping homes at optimum temperatures they also have other benefits such as reducing noise, condensation and uv penetration to decrease the rate of interior fading. Modern double glazing is devised to have a u value of around 1.6 kwh m^2 [41] however it can range up to 3 dependant on the manufacturer. It is possible to further reduce the u value of double glazing to 1.1, using argon gas[41]. Despite being approximately 5% more expensive argon filled double glazing if effective in improving the thermal efficiency of a window by upto 30%. They work based on the principle that argon is a more effective thermal insulator than air[41]. The gap between window panes can



Heat loss through single and double glazing [78] be increased to further reduce conduction without allowing convection currents to form and decrease the thermal efficiency of the window. Although they are more expensive to instal they can result in a 20% saving per year on energy bills making it an attractive prospect to homeowners[41]. With a 3.9 reduction in u value they offer a significant reduction in energy wastage decreasing energy lost through a windows to 1174 kwh a year- a 78% saving compared to single glazing. The average cost of argon filled double glazing is approximately £325 per window so although it would have a start up cost of around £1950 to £2275 but an estimated annual saving of upto £120 a year mean a payback time as little as 16-18 years. Triple glazing is also an option in reducing the energy wastage of a property however its cost effectiveness is up for debate. Triple glazing is typically Krypton filled by default as its a better thermal insulator than both air and argon, and will offer better energy efficiency. Triple glazing offers an average U value of about 0.8, or a 27% increase in thermal efficiency[41]. This can save you an average of £11.2 per year over A rated double glazing. Per year a triple glazed property will lose just 1266 Kwh heat per year. While this represents a large 84% saving compared to single glazing, it only reduces energy loss by 29% [41]compared with argon filled double glazing, wich compared with the 40% increase in cost makes it an unnecessary expense. Due to its high thermal efficiency it would be suggested to homeowners and if willing to provide the extra £130 per window would be installed in place of double glazing however on such a large scale renovation its not feasible to prove. Moreover, the manufacturing of triple glazing produces 51 Kg more CO_2[42] than a high performing double glazing equivalent and with an average saving of just 2.6kg CO_2 per year it would have a climate payback period of just under 20 years - unjustifiable considering there maximum 30 year life span[42]. In addition homeowners will be encouraged to purchase curtains and blinds that will create a good seal between window and warm air in a room to minimise the rate of transfer. When sealed the could reduce heat loss between 40 and 50% even through double glazing[43]. It would be too intrusive to specify the style of curtain a homeowner should buy, this isn't north korea after all, however magazines will be encouraged to feature long floor length curtains, which is wider than window and have 2 layers. A rating of energy efficiency will be advertised on packaging to advise consumers on which curtains are most effective at reducing energy transfer and subsequently heating bills.

Roof insulation

After walls, the roof is the second largest source of heat loss from an uninsulated building accounting for 25% of the total heat energy lost from a house[33], thats 7227.5 kWh of the 28910 kWh of energy lost per year. Roof insulation is an incredibly effective way to minimise this and if often easy to instal in all types of property. Fiberglass remains the most common form of loft insulation, since its cheap and easy to install, however as its difficult to achieve an air tight coverage heat is often able to dissipate through fibres, meaning it’s not particularly efficient[44]. Mineral wool is another common insulation in the uk it has the added benefit of being moisture resistant but it too is unable to produce an airtight seal leading to unnecessary heat loss[44]. Spray foam insulation is a fairly modern innovation in insulation involving spraying polyurethane foam between rafters to create an airtight seal, which when set contains air pockets to reduce the rate of conduction[44]. 100mm of spray foam insulation is equally efficient as 170mm of fiberglass insulation making a fair better option for smaller spaces. It is far more expensive than standard loft insulation costing £20-£50 square m[45], or £900 to £2250 per roof, compared to £6.33 per m squared for fiberglass insulation[45], £285 for your average 45 m squared roof. This type of insulation will typically reduce CO_2 consumption by 530 kg a year by saving 2650 kWh of energy. With its higher r value than wool or fiberglass insulation[45], 7 per inch for spray foam and just 2.2 for fiberglass and ability to create an airtight seal, spray foam insulation is able to create a more effective barrier against heat loss. It has the capacity to reduce heat loss by up to 91%[46] equating to a saving of 6577 kWh hours of energy and 1216 kg co2. By installing spray foam insulation you could save £250 per year[47] meaning it has a payback time of between 4 and 9 years. Fiberglass insulation on the other hand will only save you £100.70[47]. It does have a shorter payback time of just 3 years but will need replacing on average every 10 years we're as spray foam has an indefinite life time. What's more, spray foam is carbon neutral to manufacture we're as mineral wool based insulation is a huge contributor to greenhouse gases would would contribute to Solent cities carbon footprint[46]. Installing spray foam insulation would cost £750 million but result in an annual saving of 330,000 tonnes of co2.

Floor insulation

Floor insulation is a complex issue when it comes to improving the energy efficiency of homes in Solent city since it is so heavily reliant on the infrastructure of the pre existing floors in Solent city. Solid concrete floors require an entirely different approach to insulation than suspended timber floors build in older properties. 37.5% of houses in the uk have suspended timber floors[48] however due to Portsmouth's historic nature it's likely that a far higher percentage of houses were built with traditional timber floors. For this report I have chosen to assume that there is a majority of suspended timber floors in houses since we have estimated such high energy losses from our properties . For the homes estimated to have timber flooring EPS beads injecting EPS beads will be injected into cavities under floor to fill it entirely, blocking airflow to prevent convection currents. Beads often have a thermal conductivity of just 0.033w/m2k using air as an insulating gas within the beads[49]. This is proven to provide a 92% reduction in heat loss[49] or 2660 kWh a year from our standard property losing 10% of heat through its floor. This would cost as little as £200 per room[50,51] so based on our small square footage of 82.6m2 approximately £600 since our four ground floor rooms are fairly small. For £300 million pounds we would reduce our CO2 consumption by well over 1.3 million tonnes[19].

Doors

10% of the energy lost from a house is a result of poorly insulated doors[19], each home loses on average 2891 kWh of energy through their door each year. It's easy to see why since the u value of a standard wooden door is as high as 3w/ m2k[52]. The maximum u value on all new doors is 1.8 w/ m2k[52] . With such a significant reduction installing new doors seems like a viable option. In order to reach this target composite doors were designed comprising of pvc, steel, aluminium, insulating foam and glass reinforced plastics[52]. All these materials work effectively together to create a door which is low maintenance and extremely durable, but it does come at a cost- £400 each[52], 4 times the price of a regular door. In terms of energy saving replacing both doors would result in a significant reduction of energy. An average 1.7m2 door with a u value of 3w/m2k will emit 115w heat per hour in winter[52], assuming that's any day under 10 average this accounts for 180 days of the year and a total of 497 kWh per door or 993 kWh per household[52]. For the same door of a u value of 1.8w/m2k just 70w heat will be lost per door per hour or 605 kWh of heat a year[52]. This saves 388 kWh or £14.74 a year. Costing £300 more means that it would take almost 40 years to be worth the investment. Home draught proofing systems will instead be installed to reduce heat loss at a fraction of the cost. Weatherstripping can reduce draughts and prevent heat loss around doors and windows at a fraction of the cost of replacing them. Vinyl weatherstripping can create a very effective air barrier to reduce drafts around a door and cost just £9.76[55] for two 17ft rolls, ample to weatherproof 2 doors[55]. Air flow will be reduced by up to 13%, based off us case studies installing 16 ft of vinyl weatherproofing could save anywhere between 90 and 175 kWh a year[55]. With a conservative estimate of 100kWh[55] a door this results in an average saving of 200 kwh for just £10. Door sweeps can also be fitted to the bottom of a door at a cost of £14.30 for both to reduce air flow under a door[55]. In total this would cost just £24.06. Letter box insulation can also be purchased for as little as £20 to minimise draft through letter boxes. It's impossible to estimate the energy saving potential of letter box insulators and door sweeps put since they provide such low cost, easy to install options they are well worth the cost. Weatherproofing both doors may cost as little as £44.06 for a diy job or £90 for professional installation[55] but has the potential to save well over 200 kWh of energy for just a fraction of the cost of a new door.

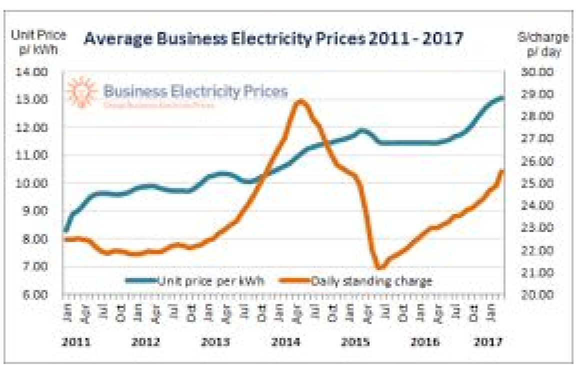
Generation

Boiler

Heating a home with a gas boiler is a common choice in the UK, with 88% of domestic heat energy generated by fossil-fueled boilers[56] due to their low cost of installation and substantially lower running costs than other sources of energy such as electricity and oil, however there lack of efficiency often results in a large energy loss meaning they do require more energy to operate than more efficient alternatives[56]. Although commonly used gas boiler are far from ideal due to their extortionate carbon footprint, even new 90% efficiency A rated gas boiler contribute an average of 210-250 kg CO_2[56] per year to the atmosphere and its predicted 47% of boilers fall short of this standard releasing 380 kg CO_2 per year[56]. For a population of 2million with 500,000 homes this equates to a yearly carbon footprint of 155550 tonnes of CO_2 per year. Clearly not carbon neutral.

Fortunately, there are a range of alternatives however they can be costly. One option is to connect our pv panels to an underfloor heating system, dramatically reducing any upfront costs since we would have already paid for there installation, however with 5 Kw solar panels our maximum energy generation per household is just 4,500 Kwh - dont even a dent in the average 24,000 kwh energy consumption for heating.

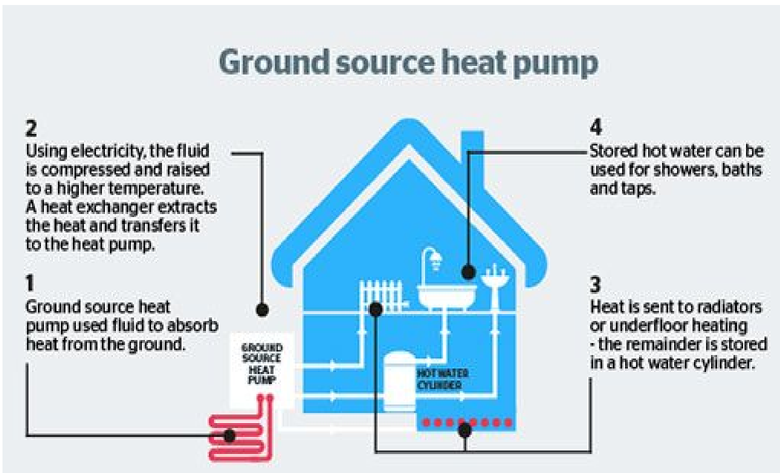
Replacing conventional boilers with wood pellet ones appear like an obvious solution, promising complete carbon neutrality due to the CO_2 stored in wood during growth. However an exterionate initial start up cost of £10,000[56] per boiler and little increase in efficiency- offering 90% efficiency compared to 80% for a conventional gas boiler[57]- they don't offer a cost effective solution.



Electricity vs gas prices uk [79]

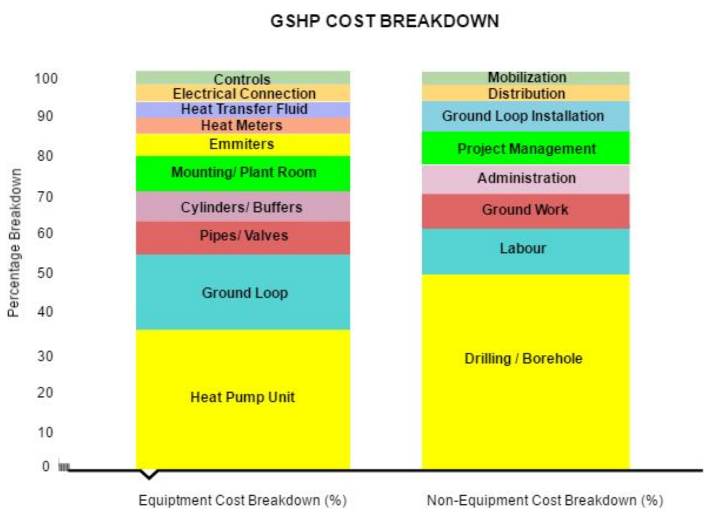
Electric boilers on the other hand, can be installed for as little £1800 for a standard 9Kw unit and bost a 100% efficiency rating[57], resulting in a reduction of 4956 kwh a year of energy . Whatsmore, there easy to instal, require little maintenance and have a 10 year life span similar to that of a gas boiler[57]. Since solent city plans to implement new low carbon methods of electricity generation there carbon output would be negligible, making them seem like an attractive prospect. Despite this, when considering their annual operational costs they become increasingly less desirable, much like your date 'the morning after'. With electricity prices in the uk averaging 13.8 pence a kilowatt hour generating[57] 19824 kwh would cost in the region of £3171.84, an exceptional amount more than the average £941.64 spent on gas despite its larger energy consumption. Installing electric boilers would cost homeowners around 237% more a year, which with the current trend in market prices is only likely to rise in the next few years making electric boilers impractical unless energy prices are drastically reduced.

Ground source heat pumps are a relatively new technology relying on the fairly stable temperature of 11-12 degrees celsius under the ground to generate heat energy. Heat from the ground is absorbed at low temperatures into a fluid inside a loop of pipe, buried underground[58]. The fluid then passes through a compressor that raises it to a higher temperature, which can be used for heating domestic water or central heating in a house. The cooled ground-loop fluid passes back into the ground where it absorbs further energy from the ground in a continuous process as long as heating is required. The systems are more efficient when cables are laid horizontally and these systems are cheaper to install however due to the limited availability of space in urban areas GSHPs have been designed with vertical piping,[58] improving there practicality. They have a range of advantages including minimal maintenance and carbon emissions of as little as 10 kg CO2 per year. Obviously they function at their optimum in warmer months but as temperatures underground show little variation based on season they are effective all year round compared to air source heat pumps they are far more efficient since they are insulated by the ground thus are a better solution despite their far higher cost[58]. Unlike gas boilers, heat pumps deliver heat at lower temperatures over much longer periods since they only have the capacity to heat water to 50-60 degrees celcius, meaning they are most effective when combined with underfloor heating to provide consistent heat at lower temperatures. Ground source heat pumps do require some electricity to run, however due to their average COP rating of 4 they are able to deliver 4 kwh of energy per kWh input into they system[58]. They are around 52% more efficient than a gas boiler[58] and would reduce the consumption of energy for domestic heating to just 4956 kwh a year. A dramatic saving. GSHPs are not widely used in domestic buildings due to their difficulty to install. They require large bore holes upto 100m deep for large scale vertical systems so may inconvenience homeowners when installed but still better to disturb your flower beds than lose your whole garden due to flooding caused by global warming. There installation means they are renowned for having high start up costs of approximately £10,000 to £20,000 with instillation[60]. They will however significantly reduce a households annual bill. Since they only require 4956 kwh to run as opposed to 24780 kWh[59] for a gas boiler they have a running cost of just £710, £230 cheaper than gas per year. In addition to this RHI payments offered by the government pay 19.8 per kwh[59] of energy generated through a



How ground source heat pumps work[80]

ground source heat pump meaning homeowners could be subsidised upto £980 a year for generating this energy brining the average[59] yearly saving to £1210 resulting in a potential payback time of as little as 10-11 years. Furthermore, a conventional gas boiler have a far shorter life span of just 10 years than the standard 50- 100 year life span of a ground source heat pump. With each unit costing approximately £1750 to replace this amounts to a total expense of £17,500[60]. By comparison the underground elements of a heat pump last for a minimum of 50 years and the heat exchanger has a life span of 25 years therefore it will only need to be replaced once in the 50 years[59]. Only 49% of the cost of a heat pump comes from the equipment itself[59]. The rest arises from installation. A heat exchanger unit accounts from just 35% of this meaning it would cost just £2200[59]. This totals to £15,200 in 50 years compared with upto £17,500 to continually replace a gas boiler and it's significantly more convenient. Although it would cost £6.5 billion to instal GSHPs to every home in solent city. It is possible to decrease this by installing 90 kwh systems connected to 7 homes instead of 12 kwh per each individual home. Increasing the size of the unit up to 90 Kwh results in a 20% saving per kwh[59]. Instead of costing £1083 per kwh a unit would cost £867 per kwh bringing the total price of the unit to £78,000 or £11,142 per home. Overall this would reduce the startup cost to £5.6 billion. Units above 90 kwh often cost 15% more per kwh to instal as a result of complications drilling and digging boreholes so 90 kWh units provide the cheapest option for installing heat pumps.



heating systems

Due to the low water temperatures generated by ground source heat pumps they are not compatible with conventional radiator systems as they are often highly inefficient and unable to evenly distribute low levels of heat throughout a room[58]. In order to warm a space radiators require large amounts to energy in order to reach temperatures hot enough to project heat across a room. Sufficient temperatures could not be reached using a ground source heat pump since water is heated to a lower temperature thus not enough heat energy would be projected to warm an entire room. An underfloor heating system is much more energy efficient than radiators using an average of 15-40% less energy[62] than conventional radiators, as it operates at a lower heat while evenly spreading the heat around the room (between 35°C and 60°C - most commonly around 50°C)[62]. This means less heat energy is wasted and a space is heated more evenly. Due to this underfloor heating is recommended in conjunction with ground source heat pumps. That being said it is renowned for its high installation costs of around £15 per m^2 ranging up to £75 m^2 [63] for more bespoke systems. Per house this would cost between £1652 up to a huge £6000 however it could reduce the energy used for heating by 9912 kWh a year resulting in a saving of £377 and a payback time of as little as 4 years. To optimise the efficiency of underfloor heating ceramic tiles should be laid throughout down stairs due to their high thermal conductivity and upstairs carpets and underlay with a thermal resistance of no more than 2.5 togs should be laid as it will not have a significant impact on efficiency [63]. Installing underfloor heating will inevitably cause disruption to a house. Thermal skirting boards are another method of heat distribution, which work well with ground source heat pumps. A study in Sweden found they had a thermal transfer ability of 50% than a standard radiator[64]. They consist of a system of hot water pipes running a skirting board in place of traditional skirting. There low position means they are more efficient than radiators for two reasons. One: they give a better distribution of convective heat. Two: they are exposed to colder air giving them a higher thermal gradient. They have a heat transfer coefficient of 12.6w/m2 compared to 8.4w/m2 than a panel radiator[65]. However, there is speculation as to whether they have the capacity to heat an entire room due to their smaller surface area than underfloor heating. Since they are considered more efficient than radiators and subsequently could have homeowners 30-40% of energy consumption[64]. Each m of skirting heating costs a similar amount per m^2 of underfloor heating however significantly less will be required to heat a house. Instead of 82.6 m2 of underfloor heating just 75m of skirting board heating will be required costing £26m[63] this totals £1950 with similar energy saving of up to 9912 kWh. Due to the ease of installing skirting board option it's far more feasible to implement in Solent city, drastically reduces disruption to households and minimising risk of unforeseen costs associated with under floor heating. It would cost £975 million to install across Solent city compared to a possible £1.2 billion up to £3 billion for underfloor heating and offers the same energy saving. Since its installed above ground maintenance of these systems is far easier.

Mechanical ventilation heat recovery

Predominantly located in loft spaces or utility rooms, MVHR systems work by extracting warm moist air from rooms such as kitchens and bathrooms and using the energy collected to warm supply ventilation air from outside the home to heat it without the use of electricity. They are extremely efficient, recovering around 90% of the heat that would otherwise be lost[66]. There design means the work continually at a low background rate. Unfortunately due the the inefficiency of many uk homes, they would be unable to be installed independently and so would also require another form of space heating supply such as a ground source heat pump. This means that they would be too expensive to install across the entirety of Solent city since each unit costs up to £3000 to instal[66] amounting total expenditure of £1.5 billion across the city. As they have the potential to save homeowners 75% off their energy bill[66] they will be advised to all new builds completed to new building regulations and pre existing homes with an air permeability of below 3 air changes per hour at 50 pascals and grants may be provided to subsidise the cost of purchase. [66]

Hot water

A household of 4 uses on average 4000 kWh of energy for domestic hot water per year[19]. While, this is significantly smaller than the amount of energy a home uses for space heating it's still a concern when striving for complete carbon neutrality as generating this energy across the entirety of Solent city will realise 370,000 tonnes of CO2 per year. Waste water heat recovery systems are one technology being newly implemented in the most eco friendly housing designs. They work by extracting heat from water traveling down the drain and using that energy to heat mains water supply. However since they only have the capacity to convert 60% energy in wastewater back to heat, savings of just 658 kWh per year can be expected[67]. Hardly justified giving their £1000 price tag[67]. Instead water meters will be made mandatory to encourage energy conservation. Low flow shower heads will be fitted saving £75 a year[68] or 1978 kWh energy a year for a cost of just £30[68]. Empathise will be placed on shorter showers and avoiding baths and washing up by hand with a washing up bowl to encourage citizens to lower their energy consumption.

Implementation

Final energy requirement

	Per Household			Solent City		
Energy in kWh	Before	After	Reduction	Before	After	Reduction
Electricity (ext space heating)	3940	2296	1644	1.97 billion	1.15 billion	820 million
Electricity (inc space heating)	N/A	3435	-3435	N/A	1.72 billion	-1.72 billion
Required from the National Grid	3940	495	3445	1.97 billion	247.5 million	1.72 billion
Gas	24780	N/A	24780	12.39 billion	N/A	12.39 billion
Hot water	4000	2022	1978	2 billion	1.01 billion	989 million
Total	32720	2517	30203	16.36 billion	1.26 billion	15.1 billion

Final cost summary

		Estimated cost	
		Per household	Solent city
Electricity	PV Panels	£4000	£2 billion
	Solar Storage	£1750	£875 million
	Generation Total	**£5750**	**£2.875 billion**
	fridge	£500	£250 million
	white goods	£300	£150 million
	TV	£200	£100 million
	Appliances Total	£1000	£500 million
	(replacements were necessary)	**£190**	**£95 million**
	Light Bulbs	£170	£85 million
	Light Tubes	£332.50	£165 million
	Lighting Total	**£502.50**	**£250 million**
	Electricity Total	**£6442.50**	**£3.22 billion**
Space Heating	Heat Pumps	£2,500*	£1.25 billion
	Skirting Heating	£1950	£975 million
	Generation Total	**£4450**	**£2.225 billion**
	Cavity Wall Insulation	£370	£185 million
	Draught Proofing	£90	£45 million
	Double-glazing	£1950	£975 million
	Floor Insulation	£600	£300 million
	Roof Insulation	£900	£450 million

	Insulation Total	**£3910**	**£1.955 billion**
Hot Water	Low flow Showerhead	£75	£37.5 million
	Hot Water Total	**£75**	**£37.5 million**
Final cost		**£14802.20**	**£7.45 billion**

*This figure is based off of the fact that an average house with 3 bedrooms consuming 24,000 kwh for heating requires an 12kwh system so each 90 kWh system could supply 7 households, however since our final design is 5 times as efficient each pump could supply 35 houses. Each 90kWh unit costs £78,000 so individually this totals just under £2500.

Running costs

	Per household		Solent City	
	Before	After	Before	After
Electricity	£543.72	£347.31	£271.9 million	£173.7 milion
Gas	£1093.64	£0	£546.8 milion	£0
RHI Repayment	£0	£840	£0	£420 million
Solar Feed in Tariff	£0	£261	£0	£130.5 million
Total	£1637.36	-£753.69	£818.7 million	-£376.8 million

RHI payments and Feed in tariffs from the government due to the installation of ground source heat pumps and Pv panels ensure that houses actually receive a payment of over £700 once the cost of electricity is deducted making houses £2,391.05 cheaper to run. Since the heat pumps do belong to the city, theoretically the council could collect the full £550.5 million yearly payment leaving houses with an annual bill of just £347.31 (assuming our methods of energy generation don't affect the price of electricity). As a result the city would pay for itself in just under 13 and a half years and after this the money could be used to fund research into upgrading the efficiency of appliances and insulation to further decrease energy consumption and meet passive housing standards across the city as well as funding innovations in carbon neutral transport and reducing social issues like homelessness.

Reduction in carbon emissions

	Before	After	Before	After
Electricity	2115kg	1850 kg	1.1 million tonnes	0.9 million tonnes
After Installation of Carbon Neutral Energy Generation	0kg	0kg	0 tonnes	0 tonnes
Gas	5324kg	0kg	2.7 million tonnes	0 tonnes
Total	**7439kg**	**1850kg**	**3.7 million tonnes**	**0.9 million tonnes**
Carbon Neutral Energy Generation	**5324kg**	**0kg**	**2.7 million tonnes**	**0 tonnes**

Once all renovations have been completed solent cities carbon footprint will be reduced by 3.7 million tonnes per year since electricity required for domestic use will be generated by a combination of domestic solar panels and nuclear and hydroelectric power. This is a significant saving not only improving air quality within the city but aiding the global mission to combat climate change and preserve our planet for future generations.

Feasible time scale

Renovation of 500,000 domestic houses along with many other commercial buildings within Solent city is by no means an easy task. Implementing all of our new technologies has a large capital cost of £7.45 billion, however in total Southampton and Portsmouth city councils receive a combined funding of approximately £130 million a year[69,70], which is currently insufficient to even meet the social requirements of the city. Instead its hoped that funding can be provided by the government as achieving carbon neutrality in solent city is in the combined interests of the nation. By requesting the government subsidise part of the cost of renovation in conjunction with the promise of refunding them RHI payments for an extended period of time after the renovations are complete its hoped that construction work could be completed within the next 15-20 years. With the government already setting aside £34 billion per year for the housing and environment sector[71] a grant seems highly likely. Solent city contains 2 million of the Uk's total 65.6 million so represents 3% of the country. If the budget were to be split equally between regions based on population size we would receive around £1.02 billion per year, but since our renovations create such a dramatic reduction in the uk's carbon footprint, by 10%, its hoped that 3 grants of £2.5 billion during the renovation process would be granted. A draft schedule is provided below

- **Stage 1, 0-5 years:** Construction of carbon neutral energy sources

  In the first 5 years we hope to achieve the construction of carbon neutral energy sources since it provided the greatest reduction of co2 consumption from the city. During this time all effort will be focused to constructing a nuclear power plant in southampton along with a hydroelectric dam outside the cities perimeter and connecting both industrial and commercial buildings to eliminate the cities dependence on coal fired power stations. While, this is taking place houses will be surveyed to assess their suitability for insulation. Plans for alternative insulating measures for Houses which have solid floors or walls will be made and a final cost estimate will be summarised based on the houses found to already be insulated to a sufficient standard.

- **Stage 2, 5-7 years:** Insulation (including doors and windows)

  Ground source heat pumps are not efficient when installed in houses with low insulation so the next stage of plan is to fully retrofit all houses to meet the building standards specified in the report. The sale of non-led lighting will also be taxed and houses will be given a 2 year deadline to swap all bulbs for LED ones.

- **Stage 3, 7-10 years**: fitting PV panels and skirting heating

  Solar panels and batteries will be installed across the city to reduce the strain placed on the national grid when heating is switched to ground source heat pumps increasing the demand for electricity. Its hoped now all appliances will have been replaced with energy efficient models as the sale of appliances under an A rating will be prohibited. Families with financial difficulties may be subsidised for the costs. Low flow shower heads will also be installed. Boilers will be due replacement in this time so skirting heating will be fitted.

- **Stage 4, 10-15 years** : Instal Ground Source Heat pumps

  Approximately 14,200 90 kwh ground source heat pumps will be fitted across the city in stages to reduce disruption during the excavation of land for bore holes. This will supply space heating to all households in the city.

- **Stage 5, 15-16 years:** Tubular lighting systems

  Tubular daylight systems will be installed as they account for the lowest energy reduction. Final modifications will be made to ensure the city functions at maximum efficiency

Carbon Capture
‘CSS’ Cycles

Eliminating remaining carbon
Up to 90% carbon emissions

Introduction

‘Carbon Capture and Storage’ (CCS) technology is a relatively new form of technology that is able to capture between 0 - 90% of the CO_2 (carbon dioxide) emissions, produced by the combustion of fossil fuels. Solent city, being so densely populated, will require a large amount of electricity per year, and an abnormally large amount of industrial processes will occur within the first six months or so of the supercity being built. Both of these aspects require fossil fuel to be used in their production, therefore meaning CCS could be a vital solution for making Solent city an attractive space for living.[1]

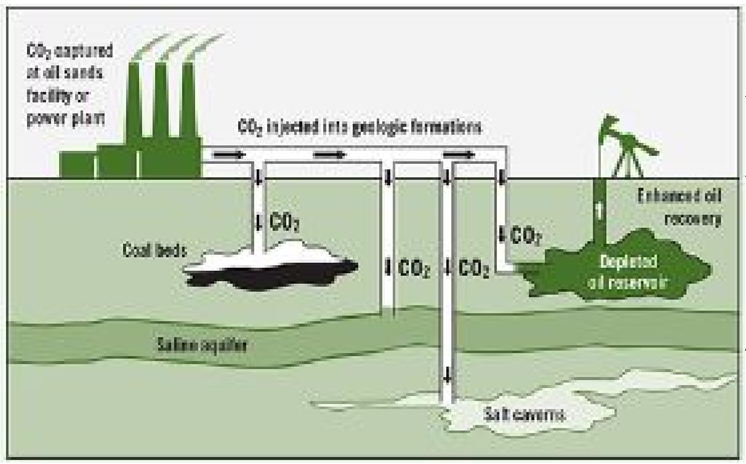
Capacity

Millions of tonnes of carbon dioxide are already transported annually (in the US) for commercial purposes by road tanker, ship and by underground piping. In the UK, the megacity of London currently emits on average 5.2 metric tonnes of Carbon dioxide per capita. As a more efficient, and modernised megacity, Solent city could perhaps produce as little as 4.8 -5.0 metric tonnes per capita. With an efficiency of up to 90%, and a population of up to 10 million, that's a potential transport and storage of up to 45 000 000 metric tonnes of CO_2. [3]

How It Works

The CSS cycle is compiled of three fundamental parts; capturing the carbon dioxide, transferring the carbon dioxide, and storing the carbon dioxide, underground in depleted oil and gas reservoirs, or deep saline aquifer formations (salt caverns).

Initially, CCS requires the separation of carbon dioxide from gases produced in electricity generation and industrial processes by either one of three methods: pre-combustion capture, post-combustion capture and oxyfuel combustion.



CO_2 is then transported by pipeline or by ship for safe storage, and finally stored in carefully selected areas (the ones mentioned above) that are typically located several kilometres below the earth's surface. [2]

At all times throughout this process, health and safety will be the main concern, and pre existing technology specialised for monitoring carbon capture and storage will be implemented. This, paired with external government monitoring will provide a more than satisfactory basis for commercial employment within Solent City.

Implementation

Cost

The cost of individual CCS projects can vary substantially depending on the source of the carbon dioxide to be captured, the distance to the storage site and the characteristics of the storage site. The cost of capturing the carbon dioxide is typically the greatest cost of a CCS project. Recent studies conclude that the first CCS projects in the power sector are likely to cost between £57 – £80 per tonne of carbon dioxide abated, although these costs are expected to decline significantly reaching £35 – £40 in the next 5 years, primarily as a result of cost reductions for carbon dioxide capture.

When researching technology for carbon capture, one must be thorough, ie comparing personal household CSS, to industrial level CSS. Obviously we can rule out the personal CSS systems; to produce such small scale projects for each household would require an insane amount of dedicated funds to keep it running over an extended period. Industrial level CSS is much more feasible - the larger the project gets (per system), the cheaper the individual materials become. For example one cubic meter of concrete is around £100, whereas fifty cubic meters is around £4 500. (Cost of concrete is averaged from a wide range of sources.) Thats a price drop of around £10 per cubic metre, and the gap continually increases relative to the size of the order.

As I said previously, CSS can capture up to 90% of carbon emissions, however the sensible amounts expect would be around 85%, purely because as we try to capture more and more it becomes less and less economical. 85% is still a fantastic amount because the trees that naturally grow in the Solent City are ar capable of capturing more than that final 15%. One option in the future would be to gradually feed the Carbon back to the flora in the the city, in an effort to permanently store it within the trees.

Similarly, while not at all necessary, the CSS system could piggyback itself onto any power plants that produce carbon in any form. This would of course be a secondary project to be completed after Solent City is complete. It would be a great opportunity, not only because it would create thousands of jobs, but also because the total cost would be greatly diminished, in that we would need no new infrastructure.

Feasible Timescale

The expected time period to get the CSS systems up and running is 6 years. This is an estimation based on the cost of workforce, as well as need for carbon neutrality, and desire to be as efficient and economic as possible. The 6 year estimation takes into account that the workforce needs to be shared throughout Solent City, and cannot run over budget merely because we are impatient.
To increase the effectiveness of the CCS system, we will be installing them in segments - the first to be built will be the largest; the main system. It will be placed equidistant from the coast and the centre of Solent City. This will reduce the amount of transport piping we will have to lay down, as well as cut down on CO^2 emissions from the vehicles that transport the rest. We estimate that the first two systems will take a year and a half to complete, whereas the remaining three will take one year each. Obviously, this estimate is the quickest expected time for completion - natural order will cause setbacks, etc. We expect that Solent City's five CCS systems will be completely finished in ten to twelve years - this takes into account the glitches in the system that would need to to be smoothed out, as well as increasing efficiency and/or getting the most economical sub-companies.

Hydrogen Dependant Carbon Reduction
Escherichia Coli

The biological solution

100% Efficiency

Introduction

Hydrogen-dependent reduction of carbon dioxide to formic acid offers a promising route to greenhouse gas sequestration, carbon abatement technologies, hydrogen transport and storage, and the sustainable generation of renewable chemical feedstocks [1], through an alternative approach based on the ability of living organisms to biologically reduce carbon. The formate hydrogenlyase (FHL) enzyme from Escherichia coli normally oxidizes formic acid to carbon dioxide and couples that reaction directly to the reduction of protons to molecular hydrogen[2]. The FHL enzyme can operate as a highly efficient hydrogen dependent carbon dioxide reductase when gaseous CO2 and H2 are placed under pressure (up to 10 bar). ?In a study by Dundee University the pressurized system was observed to rapidly convert 100% of gaseous CO2 to formic acid[3], and >500 mM formate was observed to accumulate in solution. Harnessing the reverse reaction has the potential to allow the versatile E. coli system to be employed as an exciting new carbon capture technology, with the added benefits of saleable byproducts[3].

Advantages

In addition to providing a 100% efficient carbon capture method, with zero detrimental environmental effects, This approach does not require a large amount of biomass for effective conversion[3] thus is suitable to a highly developed city, such as solent city with limited space available. E Coli, commonly seen as bad bacteria are abundant so while this practise is not yet been implemented we predict it would be fairly cheap to maintain. Hydrogen produced as a byproduct may also be sold to recuperate some of the costs of running the factories or as fuel for hydrogen fuel cell cars, hopefully decreasing there overall cost.

Disadvantages

Unfortunately this is just a study and subsequently it's impossible to predict the capacity of one of these plants or it's capital costs. Despite this we still believe it would be a useful technology in achieving carbon neutrality and still wish to use it as part of our overall design. After All someone has to be the first!

Implementation

We cannot predict how long this will take to implement since it's such a new technology, however we aim to begin building 5 plants across the city in the early stages of construction with the hope they will be fully functional in the next 20 years and able to eliminate the remaining carbon output of solent city from petroleum powered vehicles.

Cost

Again it's hard to assess the costs required to implement these plants, however since minimal specialized equipment is required we will set aside an intal £5 million to cover the cost of materials and research for the first 2 factories and reassess our evaluation prior to the construction of the final plants.

Summary
Final Plan for Achieving Carbon Neutrality

Cost and strategies

Energy

Through implementation of cleaner energy sources we have seen a huge overall reduction in the cities carbon emissions. The total yearly emissions for energy generation in uk per year stands at 138.9 billion tonnes[1], assuming consumption is proportional to population this amounts to 4.2 million tonnes for an area the size of solent city. We have been able to reduce this by a staggering 4156698 tonnes per year for just £5.2 billion due to the use of innovative new technologies. Updating our energy transmission system has ensured this can be efficiently distributed throughout the city to meet consumer demand.

Strategy:

- 250 mWe Nuclear station based in King George IV Docks
- 4 Hydroelectric dams in Meon Valley
- 3kW solar systems on 500,000 buildings

Capacity: 4,536,000 MWh

- Nuclear- 2,190,000 MWh
- Hydroelectric- 876,000 MWh
- Solar- 1,470,000 MWh

Final Carbon output: 11047 tonnes per year

- Nuclear- 6349 tonnes per year
- Hydroelectric- 876 tonnes per year
- Solar- 3822 tonnes per year

Reduction in carbon emissions: 4156698 tonnes per year

Cost: £5.2 billion

Time scale: 16-20 years

Transport

Total yearly emission from UK Transport is roughly 118.312 million tonnes a yearly. The implementation of new and advanced vehicles , will reduce the CO_2 emission from transport significantly (roughly more than 1,697,500 tonnes a year). The new electric and alternative methods used to do this will cost approximately £34 billion, this figure is the maximum amount of money that the implementation of the transport will cost. The final carbon output will vary a lot as the new transports are being implemented, for example with the hydrogen/electric cars not everyone will buy them because they are expensive, so the value will be higher than stated.

Strategy.

- Hydrogen/electric cars (1 per household-500,000)
- Electric ships/ferries (current ships/ferries systems replaced with electric system)
- Boris bikes. (70 dock stations)
- Bus rapid system (700 buses)
- Monorails (3 mile system)

Energy requirements: 1,578,162 MWh (per year)

- Monorails (137 kWh)
- Electric ships/ferries (2400 kWh per ship/ferry)

Final carbon output: 5000 tonnes per year

- Bus Rapid Transit + any petrol/diesel cars in use (5000 tonnes)

Reduction in carbon emission: 1,697,500 tonnes

Cost: £34 billion

Time scale: 5-15 years

Domestic

Estimating the carbon output of individual houses is impossible since there is such a vast variety of energy consumptions per each dwelling due to differences in construction of building and the lifestyles of the individuals inhabiting it, however we felt it was necessary to address the efficiency of domestic infrastructure to reduce our carbon emission as a city. We have deduced a strategy for reducing emissions based on standard styles of housing in the region and subsequently have been able to eliminate household carbon emissions to limit our need for carbon capture strategies. We have also tried to consider minimising disruption to public throughout the project and kept costs minimal as to allow sufficient funds to improve the transport sector.

Strategy: 500,00 newly renovated properties across the solent region

- Electricity generated via 3kwh solar panels and stored in solar batteries,
- Consumption minimised through A+ grade appliances and LED bulbs and tubular daylight systems to utilise natural light.,
- Heat generated through ground source heat pumps and distributed via skirting heating systems,
- Draught proofing and extensive insulation to minimise heat loss including argon-filled double glazing, cavity wall insulation, roof insulation and underfloor insulation.

Final energy requirement: 1260000 MWh per year (for entire city)

Final Carbon output: 0 tonnes per year (once clean energy sources introduced.)

Reduction in carbon emissions: 3.7 million tonnes per year

Cost: £7.45 billion (£4.575 billion if solar is included in generation).

Time scale: 16 years

Carbon Capture

Strategy:

- 'CSS' cycling to remove 85% of the city's remaining carbon output
- Research into using E coli bacteria to remove remaining CO_2 emissions via 5 plants set up across the city
- Remaining carbon will be stored naturally in foliage in the area, increased by domestic schemes to encourage use of allotments and improve appearance of the area.

Capacity: 16047 tonnes per year

- 'CSS' cycling- 13640 tonnes per year
- Aim for E Coli Bacteria- 2407 tonnes per year

Cost: £477400 + further £5 million for research and construction of e coli capture

Time scale: 6-26 years

- 'CSS' cycling will take just 6 years to implement
- In the following years the use of E coli bacteria will be developed to remove remaining emissions

Final Summary

Cost: £43780047740

Time scale: 20-26 years

Carbon Footprint: 0 net tonnes

Emergency Plan
Loss of 80% Generating Capacity

Identification of key services

Emergency Services During Power Outage

The health and safety of the residents of Solent City come above all else. In the event of a 24 hour power cut, where 80% of our power is lost (-9,942 MWh in 24 hours), the critical services we will keep running are:

- 999, 101, 111, 112 emergency dispatch centres
  - Police department
  - Fire department
- Medical services: hospitals, ambulances, life-critical and non-life-critical care
- Commonly used transportation systems: some traffic lights, air-traffic control, etc
- Water & sewer services
- Communications and cyber services
- Domestic/street lighting - during some dark hours of night

Solent City will have a maximum of 2486 MWh (the remaining 20%) of energy in the 24 hour emergency period. Note: our energy consumption estimates have been calculated by extrapolating current statistics (on critical services) into a city of 2 million residents. Furthermore, CO_2 emissions released from a power cut would be negligible - either absorbed by plant matter or by carbon capture.

Critical/essential services in Solent City	**Approx. maximum potential energy consumption over 24hrs (MWh)**	Note: the spare energy we have available is intended for redundancy and if necessary, for non-essential services, such as heating elderly care homes, etc.
Dispatch Centres [7]	1.1	
Life-critical Medical Centres/Hospitals [6]	592.5	
Police [8]	80.9	
Fire Department [9]	157.23	
Transport/Water [11,12]	604.36	
Street lighting [10]	0.46	

Total	**1436.55 MWh**	

Smart Emergency Services

Based on research from Belgium, Germany and the UK, more than 4000 casualties and accidents related to emergency vehicle missions are registered every year[1]. The cost of these accidents are paid by the taxpayer, since they are not covered by insurance policies. For a region of 2 million residents, if we reduced mission times for medical, fire brigade and police departments by just 1 minute, we could save about £12.3 million every year, in Solent City[1].

The modern solution is, of course, digitalisation. An estimated 43% of traffic accidents occur at junctions[2]. To reduce this, we will install wireless communication between our semi-autonomous cars, service vehicles and city traffic lights, which would be a simple upgrade to our current traffic system, but reduce the total cost of accidents by 75%[3].

This new system would be able to detect areas of congestion and redirect emergency vehicles in real-time. With obstacle-free passage, the travel time for the services would be reduced, the likelihood of an accident would be reduced and also the professionals in the vehicles would be under less stress.

Source:Car2Car Communication Consortium[4]

The wireless technology for multi-vehicle communication could easily be based on the standard IEEE 802.11 wireless LAN (WLAN) at a frequency around 5.9 GHz. As soon as two or more vehicles come in connection range, they will automatically connect. Although, since the feasible connection range will be a few hundred metres, every vehicle will be able to reroute traffic data to other vehicles along the road, in real-time, if need be.

Electric Emergency Vehicles

With the Tesla Semi being released in the early weeks of 2018, the development of commercially available emergency vehicles is already underway. The BMW i3 REx AC, is already being used by the NHS, police and fire departments in the UK[5], because its size enables quick access to and passage through city-streets. For use in emergency services, the car costs £35,600, but saves up to £2.5 million worth of fuel expenses over a 4 year lease period[5].

Source:Emergency Service Times[5]

As for current diesel-fueled ambulances and fire engines, a sustainable electric solution will likely not be economically viable (or even available) within the next 3-5 years. Thusly, their current CO_2 emissions will be captured and/or stored until an electric solution can be developed.

Cost and Implementation

New software will be installed in current Traffic Control Centres and new hardware will be installed in all public cars, service vehicles, etc, so they will be wirelessly capable of transmitting and receiving traffic data. The software would have to be initially developed and tested in Solent City, but should be ready for use within 1-2 years. However, the WLAN hardware in city vehicles will become a part of all automobile factories, creating slightly greater cost of production.

Summary of cost:

- Traffic software development - up to £700,000 in 2 years
- Implementing wireless data transfer in vehicles and traffic lights, etc. (WLAN capability) - up to £4.4 million over 4 years
- Electric rapid response vehicles (for entire Solent City) - approx £330,000 over 4 year lease
- Diesel alternatives/electric ambulances, fire engines, etc. - not available.

Total cost of optimised emergency vehicle transport over **4 year implementation-period: £5,430,000**

Appendix
Reference and Calculations

All the boring bits

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