Blott Matthews Competition

Energy For Everything (E4E)

James Ward, Peter Gambetta, Garvin Chan, Mateusz Szewc and Konrad Parzyszek - Barton Peveril College

We as students of Barton Peveril Sixth Form College have decided to take the challenge of researching and creating an essay based project of designing a carbon neutral city's energy and transport solutions. A city which won't damage the environment and will be sustainable and able to provide for the needs of future and current people. We are planning a city with modern ideas that will last and provide futuristic methods of transportation and energy generation. This city will be cost-effective and efficient providing the best solutions for modern day energy and transport problems.

Our Aim & Considerations:

Our Aim:

We aim to provide clean energy and transport for Solent city that is sustainable and reliable but is also possible within the next 10 years. We will try to keep other emissions to a minimum and are aiming to provide advanced technical descriptions of both our energy and transport solutions, accompanying this will be reasonable costs and implementation plans as well as total energy requirements for the city, which should be met with backup in case of failure.

Considerations:

We will be considering the following things throughout our project to ensure we create the most efficient and cost-effective city we can:

- Are the solutions possible within the next 10 years?
- Will the solutions result in carbon neutrality?
- Is the energy source localised or delocalised?
- Will our solutions be cost-effective?
- How efficient are our energy and transport solutions?
- How will we implement our solutions?
- Will our solutions meet the energy requirements?
- Will our solutions be effective in the long and short term?
- What are the best solutions and why?

Solent City Map

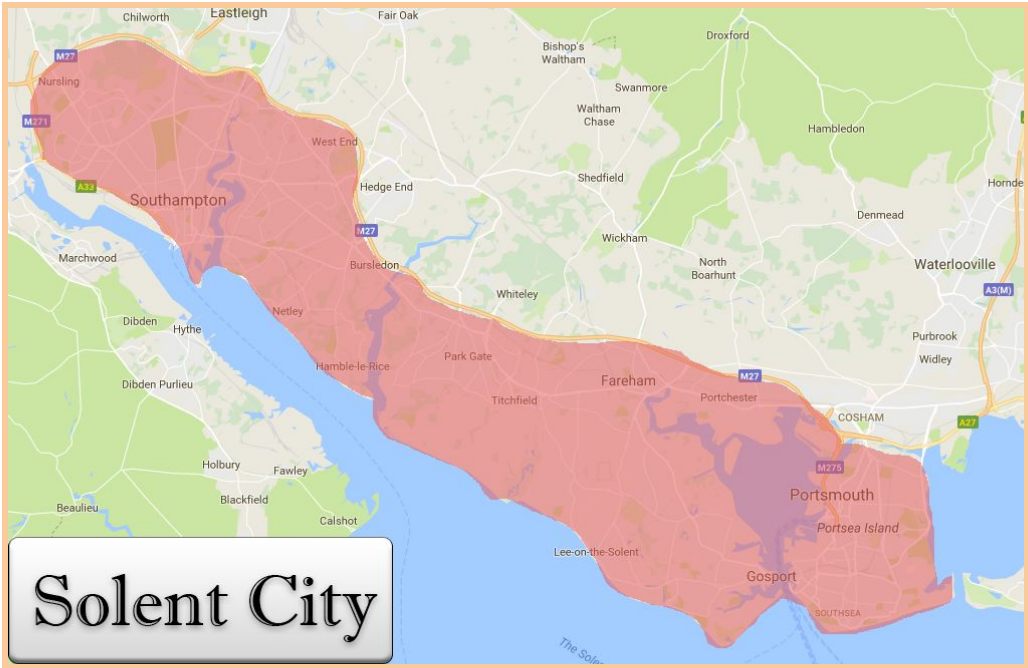

Figure [2]: *A map highlighting Solent City.*

Solent City is a Southern City that consists of two pre-existing cities known as Southampton and Portsmouth and the areas between them. Solent City is designed to be a carbon neutral city which would make it the cleanest city in the entirety of the United Kingdom. The city would be governed by a single council in charge of the entire area perhaps with smaller divisions specialised in certain areas. The average size of Solent City is estimated to be around **212.44 km^2.** Which is slightly larger than most cities in the United Kingdom however still much smaller than London, Leeds and Sheffield. However this value does not include the sea area surrounding the city's land.

Energy

Energy Source:

We have decided to use a combination of Solar Energy provided by Photovoltaic Cells within households and a large solar facility positioned on and offshore within Solent City. The energy produced will be stored within batteries that will then provide energy to the entire city when needed. The combination of two power methods provides us with more than enough energy and will provide an excess of energy that will be used if our solar panels are performing inefficiently. The excess of energy will always be available in times of need.

Distributed or Centralised:

Our energy solution is distributed, we have solar panels that will be positioned upon new homes as well as a dedicated centralised solar farm. These energy sources situated on homes will be connected to a battery stored within the property. Any excess energy will be diverted to larger batteries situated in centralised locations. The larger energy farm will also be directly connected to these batteries which will provide energy for non-domestic use within industry and transport whilst also providing a backup if the homes ever need extra energy.

Environmental Impact:

Our energy solution is carbon neutral as it uses the power of sunlight and photovoltaic cells. This is a renewable technology which has no net carbon output, whilst also keeping other environmental impacts to a minimum. Our solution has the problem of land use and potential habitat destruction however this will always be the case and as we are starting on a mostly clean slate there will be no previous habitats.

Energy Requirement Analysis - General:

We based the energy requirements from the official records of the UK in 2015. The country as a whole in **2015** used **141,215.3 Ktoes (Kilotonne of oil equivalent)** which is equal to **1642333.939 GWh** with a population of **65,110,000** people. This is split into the following sectors, accompanied by the equivalents in **GWh.**

Energy Sector	Usage in Ktoe	Converted to GWh
Industrial	24,361	283318.43
Transport	54,748.3	636722.729
Domestic	42,143	490123.09
Other	19,963	232169.69

Next we divided by the population of **65,110,000** and then multiplied the resultant numbers by **2,000,000** and this provided us with these results as an average energy requirement for a city of 2 million people, divided into sectors. However we changed the calculation for Domestic as we discovered there was an average of 25 million homes in the UK so we divided the total domestic energy usage by the total houses. We worked out that an average of 666,667 homes would be required for a population of 2 million people with 3 people per home. Therefore we rounded up to 670,000 homes to provide extra housing.

Energy Sector	Calculation	Energy Usage (GWh)
Industrial	283318.43 / 65,110,000 * 2,000,000	8702.76
Transport	636722.729 / 65,110,000 * 2,000,000	19558.37 (Before) 3,877.88 (After)
Domestic	490123.09 / 25,000,000 * 670,000	13135.298 (Before) 4542.34 (After)
Other	232169.69 / 65,110,000 * 2,000,000	7131.61
Total	8702.76 + 19558.37 + 13135.298 + 7131.61	48528.083 (Before) 24254.59 (After)

However, these values will be reduced when paired with our energy saving technologies that can be seen below. This will cause a drop in energy use in the Industry and Domestic areas. As well as this, Transport will change from this value due to the new transport system we will be introducing, this is detailed in the transport section which is deeper in this document. However the changes can be seen above next to the “**(After)**” tags.

Energy Saving Technologies:

Homes built within Solent city will be filled with energy saving technologies designed to reduce the amount of energy used in the domestic sector. All homes will be insulated to ensure warm winters however not too much to prevent having homes that are too warm within summer, this will prevent some people from wasting energy powering air-conditioning or fans. As well as this, homes will be fitted with LED lights which are known to be up to 90% more efficient than traditional halogen bulbs. Also, boilers will have Valve wrap, a form of insulating that reduces heat loss from the boiler, meaning less energy is wasted heating the surroundings instead of the water. Furthermore, all our homes will have power optimisation, this will alter the incoming voltage to maximise energy efficiency and reduce costs for homeowners. All buildings will also be fitted with solar panels designed to capture extra energy and store it within the local home battery for later use, reducing the need of using energy from the grid system.

Energy Saving Technology	**Energy Reduction**
LED Lights	91.25 - 9.13 = 82.12 kWh
Boiler Valve Wrap	10 - 20 %
Draught Proofing	10 %
Cavity Wall Insulation	35 %
Total	65% Energy Usage Reduction & -82.12 kWh

Redundancy For Critical Services:

In the event of up to 80% energy supply lost we would prioritize our remaining power to emergency services such as health care within hospitals to ensure the safety of people in life-threatening situations. As well as this, energy will need to be maintained with the Maglev system that is planned, this will prevent crashes and still provide a form of public transport whilst in a power outage. Unfortunately charging stations for vehicles will have to shut down to maintain energy as best as we can. Homes should be able to run still since they will have their own backup systems (more below) that is stored within the household. However if this was ever not the case we would advise homeowners to use their electrics sparingly during this time to reduce usage. Since we have decided to build a large centralised battery system we have planned for backup systems to be used in situations like this.

Battery Backups - Distributed

Each home will be equipped with a secondary battery that will stay fully charged as it should only be used if the first battery runs out. This will be designed to only happen in cases of emergency for example if there is a problem with the grid supplying energy to the first battery or the solar roof is not functioning efficiently enough. This will allow the residents of the home to continue using electricity for things they are certain to need during this downtime. However people will be advised to ensure most of their appliances are off to prevent energy waste. The same concept will be applied to the electric cars, buses and hybrid planes used throughout the city, this will help prevent breakdowns and provide enough energy for the vehicle to reach the nearest charging station or safe location. However the vehicles should not run out of energy often as the routes used will be checked to prevent this from happening, ensuring there is a charging station on route if required. Due to this the only time these batteries will be used is in times of power outages such as this proposed situation. This will allow transport to continue working for a full charge however these batteries will not be able to be recharged until the energy supply is back however they shouldn't run out often during one of these rare events.

Battery Backups - Centralised

Furthermore, our proposed large energy storage facility will be equipped with reserve energy systems designed to provide energy to critical services such as hospitals, the maglev system and security systems. This will ensure that even when we have an 80% power supply loss we will still be able to provide energy from a backup storage to power critical services for at least 24 hours or for as long as the power outages are occuring.

Critical Services Energy Requirements

Critical Service	Energy Required (24 Hrs)	Power Supply
Hospitals/Healthcare[1]	7,385.338 kWh per hospital	Reducing our energy system to **20%** production whilst at it's at our lowest efficiency value of **70%** would provide us with a total of **13.31 gWh per day**. Which can easily power these critical services, even without the backup energy already stored for emergencies.
Maglev System	113.441 kWh	
Security Systems[2]	Minimal	
Homes	12.445 gWh	

[1] 50 kWh/m2 per year highest cost of a hospital energy. Southampton General is sized an average of 53912.971 m^2.

[2] Energy consumption of security systems cannot be found however it will be a very small value therefore won't affect the calculation significantly.

Comparing Distribution & Centralisation:

Those two types of energy solutions have advantages and disadvantages for both sides. Distributed energy is a type of energy which involves methods that generate direct current (DC) such as solar panels. This means that each of the batteries has to have a DC to AC-DC (alternating current) conversion element which reduces the risk of electrocution which makes the distributed energy safer. Secondly, these energy supply methods are good because anyone can install a power supply for example a solar panel on their roof. This is because distributed energy methods are usually compact and available to use in any place.

However, one of the biggest advantages of centralisation is the fact that everyone has one provider of energy. This means that the provider has a much bigger energy supply which usually means that there is always a reserve of energy in case there will be a spike in demand. Furthermore if everyone is under one supplier of energy then the supplier can manage which area needs the most energy and so energy can be prevented from waste. The fact that there is only one provider means that the areas of high demand can be easily managed.

Energy Supply Strategy:

Our energy supply strategy consists of using a centralised solar farm as well as distributed solar panels. The distributed domestic solar panels will be positioned onto individual homes and connected to an inverter to convert the DC power to AC current. This will connect to a domestic lithium-ion battery which will store the generated energy for use over time. This will be connected directly to the buildings electrics allowing use at any time. The battery will also connect to a grid system which can provide and draw power from a centralised battery location whenever necessary. Excess power generated from homes and industry buildings can be sold to the grid and stored in the larger batteries for use in other homes or non-domestic locations. The larger centralised batteries will store the energy provided from our large solar facility which will be used to power other services without their own method of energy generation such as any vehicles within the transport sector as well as being used as a backup system in the event that buildings are unable to generate the energy they need to run. The centralised battery locations will be designed to easily supply the entirety of Solent City. These batteries will be connected to the new solar farm developed which will provide more than enough energy to keep the city running. Since we are storing the energy in large centralised batteries we are able to transition straight to renewable energy as soon as we open the city. If due to a some sort of disaster both methods of electricity generation fail at one time (which is very unlikely), the city will rely on the previously generated energy stored in large batteries based in the city. There will be enough large capacity batteries to ensure that the energy inside will be enough to run the city until energy generation methods can be reinstalled and working.

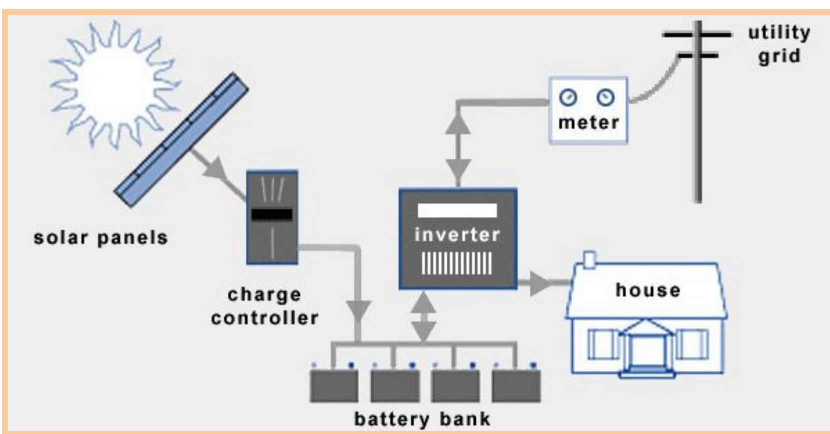

Figure [3]: *An example diagram of the solar panel energy system connected to a house and batteries.*

Detailed Technical Solutions For Energy Generation:

Solar Panels

Centralised Farms:

Our energy supply system will be partially powered by the use of a local solar farm. The solar farm will be designed similarly to the example of Landmead Solar Farm, its purpose will be to provide energy to the people and services within Solent City. Solar technology has come a long way in the recent years and will only continue to grow and become more common. With this rapid increase of attention solar technology is only going to become more affordable and more efficient, this sets up solar energy to be the perfect solution to powering a city carbon neutrally as it will continue to improve. The energy generated from this farm as well as the distributed solar panels should provide the city with enough energy to power the entire city. As well as this, during winter months where the sun shines for less time, the storage batteries will store excess energy generated which will be used during this time. This provides energy redundancy for the any situations that may need it.

Figure [4]: *Landmead Solar Farm, The UK's largest Solar Farm is Solent Cities solar farms will be based off.*

Our centralised farm is set to use 46MW Solar Panels much like Landmead Solar Farm, new research has discovered a way to create solar cells that produce energy at over 100% efficiency, This technology discovered by the National Renewable Energy Lab will provide the basis for exceptional levels of energy generation from our solar facilities, we believe that within the next 10 years there will be a definite way to implement these solar cells into solar panels that will be used in our farm and houses. We have worked out that by using a solar farm the size of 224 Km^2 we will have enough panels to power Solent City and provide energy redundancy for an efficiency from 100% to 70%, with these new panels this seems very possible to achieve. The total energy generated by solar farms and solar roofs can be seen in the Energy Generation section as well as the excess they produce.

Distributed Panels:

Furthermore, We plan to have solar panels built into the roof tiles of our newly built homes. This arrangement of distributed solar panels has been used elsewhere to create a fully self-sustaining housing development in Schlierberg. So therefore if we follow these designs but use them on a larger scale the homes should prove to be fully sustainable whilst having back up for times when this is not the case. The example housing development named the "Solar Settlement" can be seen below and was built between 2005 and 2006. Solar technology has advanced so much from this time which should mean if we follow a similar but updated design it should easily create a self-sustainable solar housing development within Solent City. A further example of this technology is the new "Solar Roof" created by Tesla, these high efficiency panels are built into the homes whilst being much more resistant than traditional roof tiles. We plan to create a housing development with the design of the previously mentioned Solar Settlement but with newer technology similar to the Tesla panels and the new 100% efficient solar cell. Using this technology we should be able to develop an entire city's residential area to be fully self-sustainable as even at 70% efficiency these roof panels will provide more than enough energy to power these homes. This will provide Solent City with a fully self-sustainable home system that is also carbon neutral.

Figure [5]: *The Solar Settlement and the Sun Ship, developed in Freiburg, Germany.*

Figure [6]: *The Tesla Solar Roof, An example of the design we plan to incorporate into our solar homes.*

Traditionally Monocrystalline solar panels would be used for solar energy which had been specifically designed to be very efficient, as well as being optimised for commercial use. Although new technology has recently been developed that allows over 100% quantum efficiency from solar cells, which is extremely better than traditional cells that often have a maximum efficiency of 22%. We plan on implementing this technology into our panels to provide the most efficient energy system that can power an entire energy and use the least amount of space whilst still having backup energy. Despite the likely cost of these new cells, ultimately all spendings be earned back in savings from the renewable energy. The new cells used are known as Quantum Dot Solar Cells and use Semiconductor nanocrystals to harvest the light for use in energy generation. The extra efficiency comes from stacking layers of the Quantum Dot solar cells, the increase in layers will reduce the bandgap within the solar panels, causing the increase in efficiency. This technology is being researched by many people and many solar panel concepts are being developed therefore it is very likely that within the next 10 years these panels will definitely be possible however if not at full 100% efficiency our system still allows for as low as 70% which should definitely be achievable. Our solar panels will be placed on roofs aimed to be tilted at 45 degrees, this is because 45 degrees is the best angle for all year round use of solar panel energy generation. Solar panels usually don't break but on the off chance they do or perhaps in the case that Solent City hasn't received much sunlight for awhile. The energy system should still be able to run by using the energy generated from backup energy already stored, this should suffice until the panels are fixed or the sun comes back.

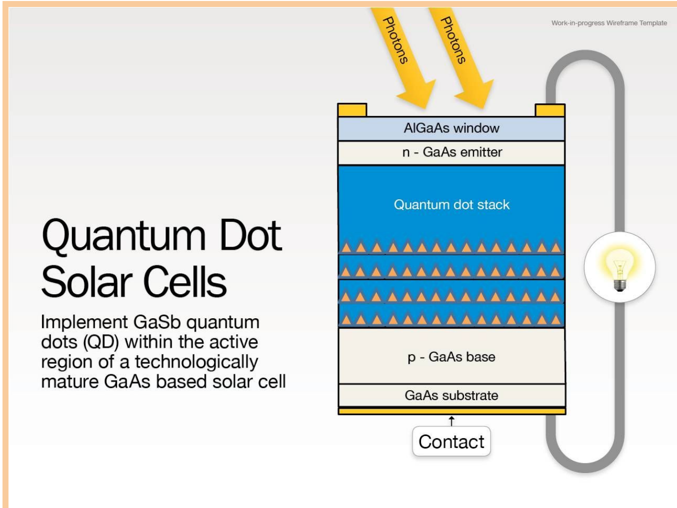

Figure [7]: *An example diagram of the Quantum Dot Solar Cell structure.*

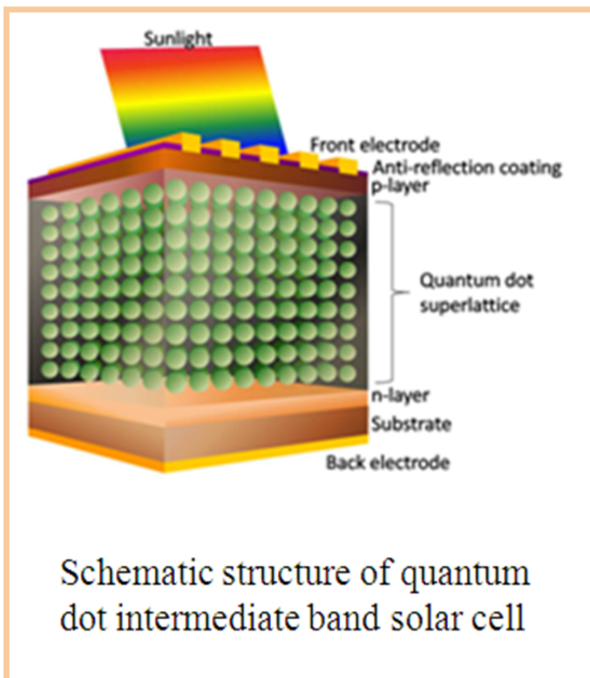

Figure [8]: *Another example diagram of the Quantum Dot Solar structure.*

Battery

Centralised Storage Facility:

The energy we develop will be stored within a centralised lithium-ion battery storage facility. This will be modelled after the Hornsdale Power Reserve in Australia. However ours will be designed with a larger capacity with the purpose of storing power for an entire city. This system is a 100MW system however it is very likely that this technology can be developed much further in the near future. This will provide the perfect storage system for powering Solent city, the system will be designed to hold an excess of energy as well as backup reserves for critical situations, this should allow the city to continue working even in the most energy strenuous situations.

Figure [9]: *The Hornsdale Power Reserve is an example of the inspiration for our Centralised Battery Storage.*

The technology inside the power storage facility features lithium-ion batteries. These work by moving electrons from one side of the battery to the other. The energy generated from the moving electrons can be used to power anything electrical. The inside of the battery features an anode and a cathode which can be seen pictured in the diagram below. In most cases the anode is made from carbon whilst the cathode is made from a form of metal-oxide. These two electrodes are placed apart from each other within an electrolyte, this electrolyte features lithium ions. When the battery is used the positively charged lithium ions are attracted to the cathode upon this happening the cathode become more positively charged than the anode, this then attracts negatively charged electrons. As the electrons start moving towards the cathode they are forced through the electrical device which generates electricity that will power them. These batteries can be recharged which make them ideal storage devices. This happens through the movement of the lithium ions going from the cathode to the anode as this happens the battery becomes restored for later use. Many of these batteries are used within this huge power facility and on a much larger scale. This will allow storage of much more energy, enough to power an entire city.

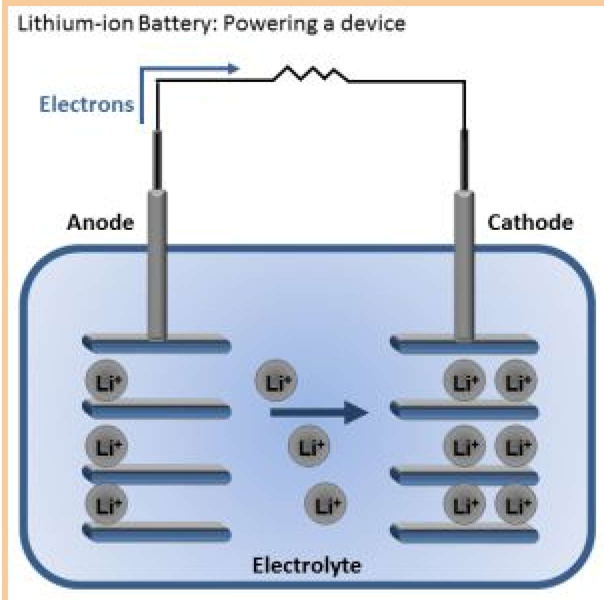

Figure [10]: *A diagram that displays the inside of a Lithium-ion battery.*

Distributed Storage Batteries:

The figure below shows a [Tesla Powerwall] which provides 13.5kWh of storage capacity is a perfect example of the distributed batteries we could use to power the city's homes. This battery can output about 3.68-5kW of power at the maximum. Tesla has stated that these powerpacks can run a home purely on the energy stored in it for a full year, this design will be implemented into our plans and will only improve as time goes on and therefore through implementation of batteries similar to these into our new homes we will be able to provide full energy storage for each individual home easily. Each home will also feature an emergency backup for critical situations such as power outages, these batteries will be charged by both the distributed and centralised panels ensuring they are never uncharged. Despite being relatively expensive for domestic use at the moment, the technology will only get cheaper as time goes on. This provides the perfect base for self-sustainable homes in a carbon-neutral city.

The battery functions in a very similar way to a lithium ion battery which description can be seen above. Also, lithium ion batteries store direct current. Therefore, the electricity has to be converted from alternating current because our generated energy will use alternating current.

Figure [11]: The Tesla Powerwall, an example of the distributed batteries we aim to use in Solent City homes.

Energy Distribution:

Our electricity will be stored in the batteries mentioned above however to distribute the energy from our large centralised battery system we will require use of distribution substations placed within the facility. These will connect to a transmission system which will lower the transmission voltage to a value ranging between 2 kV and 35 kV using transformers. The electricity will then be distributed using primary distribution lines which will connect to distribution transformers that will lower the voltage again to utilization voltage that can be used by most devices. This will be used for high energy demanding buildings as well as public charging stations and transport. However for homes, secondary distribution lines will connect in the same way to the distributed battery storage packs placed in each house however this will only be done when the solar roof tiles are not providing enough energy which should be a rare occasion. The solar roof energy will be stored within these distributed powerpacks as a primary source of energy with the larger centralised battery as a secondary energy source. The house will then connect to that powerpack and have all energy required to run whatever is necessary whilst also keeping a backup.

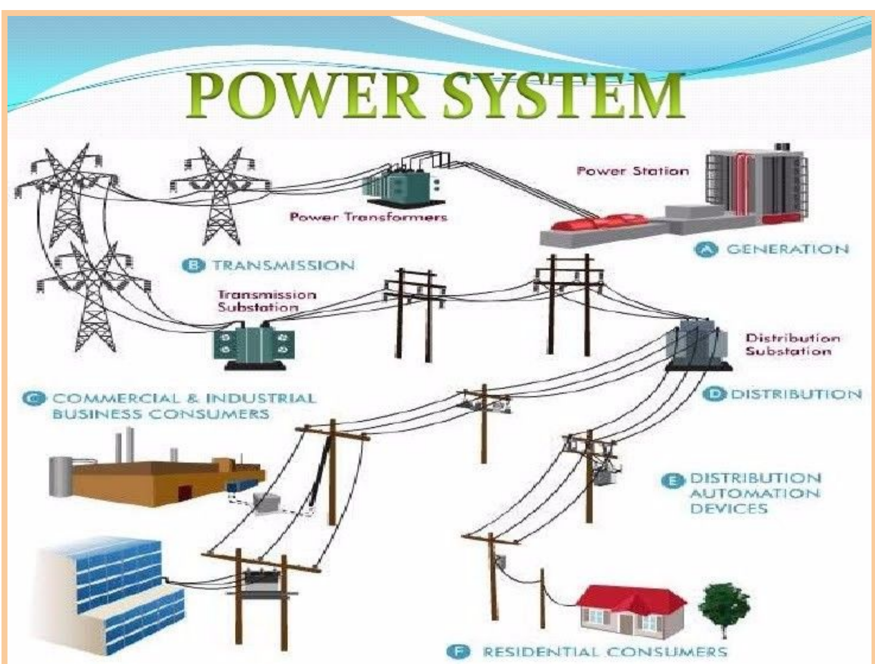

Figure [12]: *A diagram showing an example of a system of energy distribution without the powerpacks we plan to use.*

The distribution system will feature many transformers tasked with reducing the voltage of the electricity being distributed throughout the city. These transformers work by using an alternating current, that passes through a primary coil which is wrapped around the transformer core the changing current generates a changing magnetic field. This induces an alternating voltage into the secondary coil which is then transported out and used for powering devices. The voltage on the secondary coil can be controlled by the amount of turns of the coil on each side. The system uses both Step-up and Step-down transformers, the first uses more turns on the secondary coil whereas the second uses more turns on the primary coil. This changes the voltage to the required level. Step-up transformers are used to transport electricity as moving energy at higher voltages reduces energy loss, and step-down transformers are used to reduce this voltage for domestic and commercial use.

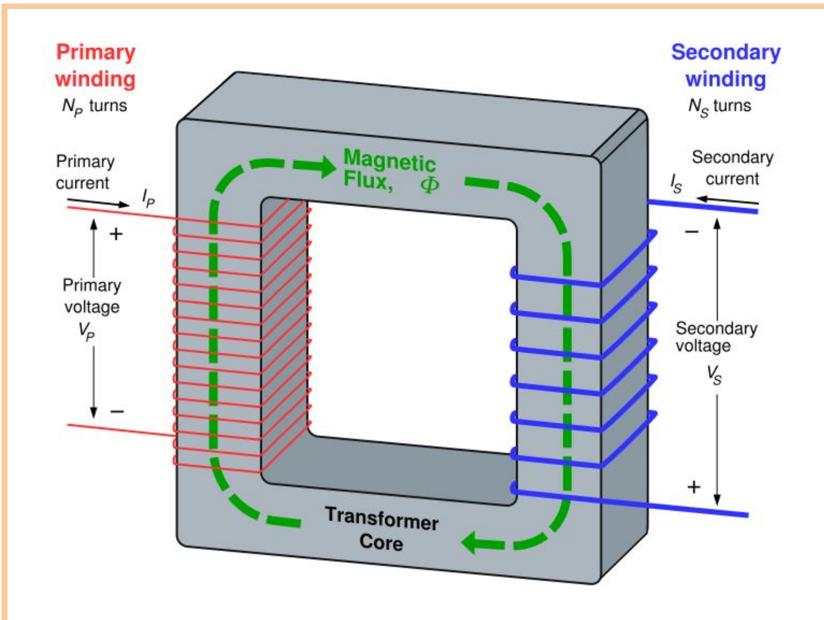

Figure [13]: *A simplified diagram of the operation of a transformer.*

Energy Generation Values:

After calculating we have worked out that our energy solution will be able to power Solent City at all times of operation as long as we are producing energy at a minimum of **70% efficiency.** The values below show the energy generated by each method as well as the efficiency of each method and if there is any excess energy left over for storage within the batteries which will be used if the solar panels begin working un-efficiently (under 70%) for a period of time.

Energy Method	Energy Generated (gWh)	Efficiency	Excess (gWh)
Solar Farm - 224 Km^2	28207.2	100%	10440.986
Solar Roof	6488.665	100%	
Solar Farm - 224 Km^2	19745.04	70%	32.226
Solar Roof	4542.065	70%	

Therefore we can prove our system will work and still have an excess of energy to keep the backup batteries charging as long as our system is operating at above **70%** efficiency or above. When operating at **70%** efficiency a larger size of farm will be required therefore we will use a solar farm the size of **224 Km^2** Which will provide more than enough excess energy when operating at **100%** and just enough when operating at **70%**. This will allow continuous charging of our backup batteries which will prevent the chances of a blackout as we will always be gaining energy and when we aren’t we will have energy stored to power the city until the solar cells are functioning again.

Transport

Transport Solutions Concept:

We have researched many solutions for the transport methods that are able to transport people very efficiently whilst still being carbon neutral. To begin we have designed an inner transport system, this consists of Autonomous Electric Cars and Buses, this will allow fluent driverless travel that has no harmful emissions that could damage the environment. This is complemented by our outer transport system. This will consist of a form of maglev trains as well as hybrid electric planes. The maglev trains are designed to transport passengers around the entire city as well as out to nearby towns and other cities in the future whilst being fully electric and producing zero carbon emissions. As well as this, the hybrid plane will be able to efficiently transport citizens to neighbouring countries whilst generating reduced harmful emissions. All of our ideas have been researched to the best of our ability to decide if the example used will be fit for use within Solent City. However we have been unable to find an example work of an electrically powered sea transport that would be efficient and useful for the distance it will have to travel, therefore we will be keeping the traditional sea transport and introducing carbon capture systems, these are designed to remove excess carbon from the atmosphere that will be generated from sea transport and air traffic that may not suit the requirements of the city, this also allows longer flights to be achieved from other types of planes whilst still producing no net carbon emissions. All the transport systems should work fluently together in the city providing perfect public transport solutions with the buses and maglev trains as well as personal travel with the cars and traditional bicycles. Whilst keeping up with the demands of air and sea travel using traditional methods enhanced with new technology.

Detailed Technical Designs For Transport Systems:

Autonomous Electric Cars (Tesla Model 3/S)

As a team we've decided to use autonomous electric cars which will be based off of the Tesla Model 3/S. These cars now offer full autonomous capabilities but due to government regulations, legally the cars aren't allowed to be fully autonomous. The cars use 1 or 2 electric engines which are situated at the back or/and front of the vehicle.The biggest pro of having an electric motor is that the torque is available immediately. This means that the top model of the Model S can accelerate to 60mph in 2.5s making it extremely useful for fast but safe transportation that will be featured in the vehicle we use. This acceleration is due to the fact that there is a single fixed gear and the car doesn't have to rev up to a certain RPM range in order to get a maximum torque value like it is present in internal combustion engine.

Figure [14]: *An example of the Tesla Model 3 that we are using as an inspiration for our transport system.*

Tesla offers the biggest autonomous features currently available in the world. The car can drive itself all the time but requires the driver to touch the steering wheel every 1 or 2 minutes. In order for the car to have such capabilities, it is equipped with 8 cameras which create a 360 degree image for the cars software. The cameras have up to 250 metres of range. The car is also equipped with 12 ultrasonic sensors which have a specific feature of detecting whether the object is soft or hard. If the weather gets bad the cameras are supported with a radar that faced forward of the car. It uses a specific wavelength to overcome any conditions such as rain, fog and dust. The car will include enhanced autopilot which allows additional features such as automatic speed changes that occur due to changes in the weather conditions. Also, the car can automatically change lanes without any action from the driver, it can exit the motorway and go onto another road or park itself. Although the normal autopilot or even the enhanced autopilot of the Tesla now can't drive itself fully it will be possible in the future because the cars already feature the hardware to drive from one place to another without the driver doing anything. The car will even sync with the driver's phone and its calendar to see what is planned for the day and take the driver to that set destination automatically. This will prove very useful for citizens within Solent City. Despite the example Tesla being unable to drive fully autonomous at the current state, this feature will be implemented into the cars we use as by then the technology will like be more advanced and once fully tested and safe can be enabled to allow fully electric and autonomous travel.

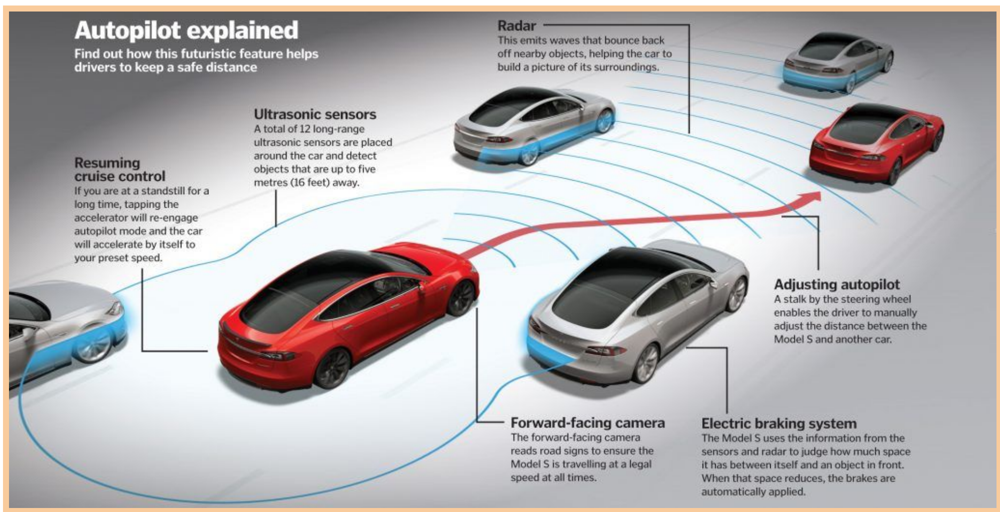

Figure [15]: *An example diagram of how the autopilot system in the Tesla Model S works.*

Autonomous Electric Bus (Proterra Catalyst)

The Proterra Catalyst Electric Bus is a perfect example of an electric bus we could use to provide transport throughout Solent City. It uses a standard electric traction motor to power the vehicle, which is situated at the back of the bus, this is where most of the technology is. This includes: the transmission, the air dryer, the cooling manifolds, the motor controller, the air compressor and the DC/DC converter. All of these components work together to create a bus which can be eco-friendly and able to have a manageable range of miles. The electrical energy is stored in the Teravolt Energy Storage system which is located under the bus and is mounted in the floor cavity. The roof the bus contains many components; which includes a roof mounted all-electric HVAC system (air-conditioning) as well as a Fast Fill Charge Blade and Alignment Scoop which allows 12-15 miles per 5 minutes of charging time. The bus is able to carry 40 seating passengers and some standing passengers creating useful transport solutions that can span across the entirety of solent city. The buses will travel special routes originating from electric charging docks situated within Bus depots around the city. This way the buses will never run out of charge as the routes will be designed to fit the charge capacity of the energy storage system which can be up to 350 miles. Since the bus is electrical it has zero emissions which will dramatically reduce the carbon emitted by public transport.

This system will eventually be updated to a newer bus model that is currently in development, this bus is fully autonomous as well as electric which will make transport even easier and remove the need for drivers and the risk of human error. This new bus will likely use radars and sensors to determine threats upon the road and surroundings. These buses will be programmed to follow the specifically set out routes used by the previous bus. The system will be similar to a sat nav system controlled by satellites however the buses will respond to traffic situations finding the fastest route to ensure it is never late when arriving at bus stops.

Figure [16]: *The Proterra Catalyst used to inspire the design of our electric bus.*

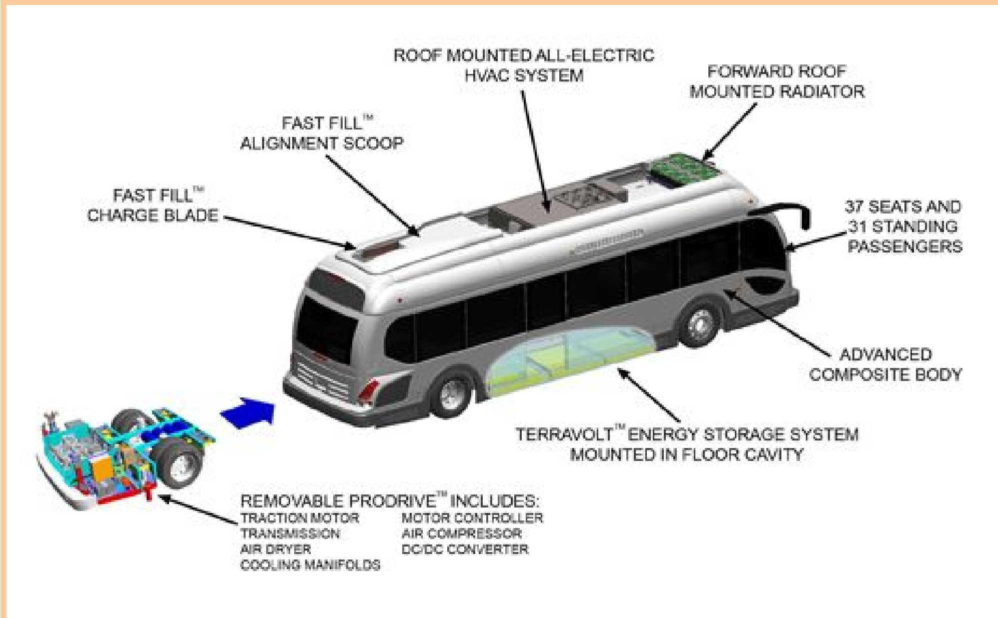

Figure [17]: *An example of how the Proterra Catalyst electric bus is designed.*

Maglev Train (Transrapid)

We have decided to use maglev trains to provide transport throughout our city and to the outwards to other areas. Maglev trains do not only have the potential to travel at extremely fast speeds but as well as this they make extremely efficient transport methods due to the maglev technology they use. This means that maglev trains are likely to be a perfect method of transport for Solent City. A good example of this technology being used commercially is the Shanghai Maglev Train system, this uses Transrapid train carriages developed in Germany. The system is used to transport passengers from the Shanghai Pudong International Airport to the city center with multiple stops on the way. Therefore we feel this technology could be used within Solent City to efficiently transport everybody around the city and potentially create transport links to other cities within the country.

Figure [18]: *An example of the Transrapid Maglev Train.*

The Maglev train systems use the technology that can be seen in the image below, four magnets positioned in a box formation are supercooled which generates a magnetic field around 10 times stronger than normal magnetic fields, this is enough to support a train. The magnetic field interacts with magnetic loops built into the maglev train, this generates electric current, which causes the generation of another magnetic field. The maglev trains use 3 different types of loops to ensure the maglev works, the first loop is used to create a magnetic field which causes the train to hover around 5 inches above the rails. The next loop uses a magnetic field to ensure the train stays stable horizontally to prevent the train from tipping. The third and final form of loop uses magnetic attraction and repulsion, the magnetic fields generated are designed so that they attract the front of the maglev train whilst repelling the back. This causes the train to move forwards, since the only friction affecting the train is air the train journeys are much smoother than traditional trains. The lack of friction and repetition of the magnetic fields allows the maglev to reach very fast speeds.

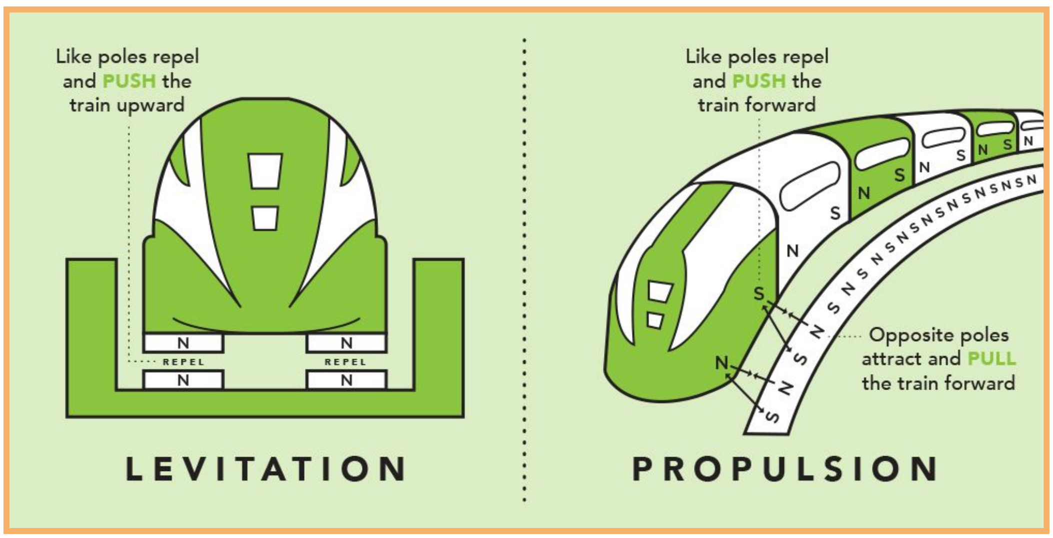

Figure [19]: *A technical diagram displaying the maglev technology.*

Hybrid Plane (Airbus E-Fan X)

A hybrid plane which we believe would be good to use is the Airbus E-Fan X which is demonstrated on the picture below. It contains of a hybrid electric system that is used to power one electric motor that is used to fly the plane as well as 3 normal motors, although this plane is not fully electric, we believe it is the most efficient electrical plane that is currently being developed for use. The new plane is based off of the original British Aerospace 146 planes with a new electrical enhancement, these planes are short-haul planes meaning the plane will be able to travel to neighbouring countries with ease still providing transport out of the country. The lack of long-haul planes is not too much of an issue due to the fact we are close to London which will provide more airports for long-haul flights.

Figure [20]: *An example image of the Airbus E-FanX.*

On the diagram below the E-FanX is shown technically. This design of the plane has 3 companies that supply it with technology; these are Airbus, Siemens and Rolls-Royce. These companies are all large names and very powerful, the technology they can all provide will prove extremely useful in pushing the limits with fully electric and hybrid planes, hopefully paving the path for fully electric planes to be developed soon. The plane uses a 2MW motor instead of a turbofan engine. At the rear end of the plane there is a gas turbine which is used together with a 2MW generator to produce energy for the plane. This energy is then used to power the electronics on the plane via the power distribution centre. This decides where to distribute the energy efficiently so that the plane runs correctly. Although this is only a hybrid plane it's the best currently available in terms of carbon emissions that we could find. However, we will be implementing carbon capture which leave us with a zero resultant emission of carbon dioxide. To add to that on the Airbus' website it is said that the partners are wanting to achieve a goal of reducing CO2 by 75%, NOx by 90% and noise by 65%.

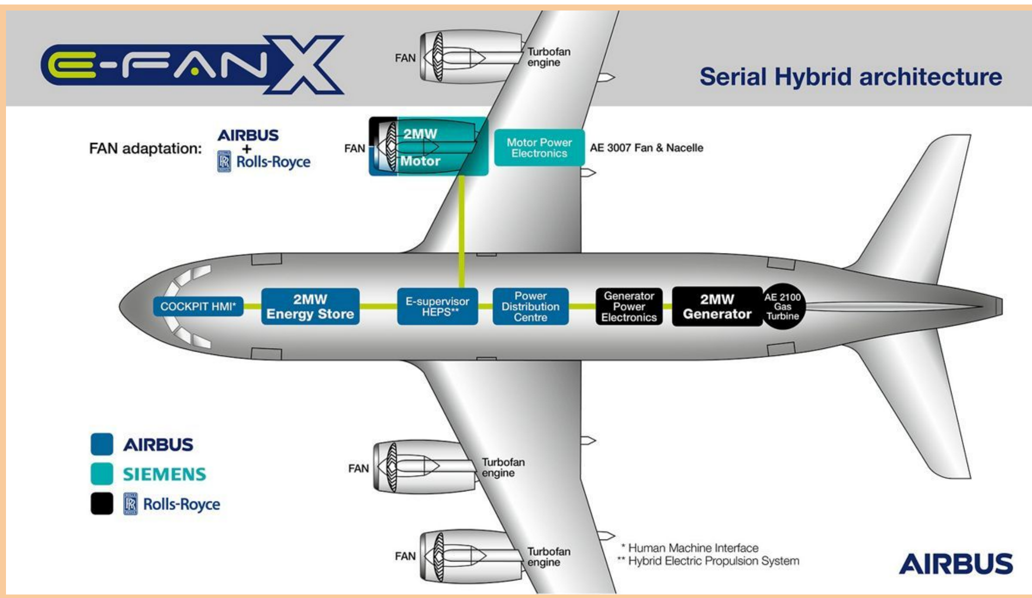

Figure [21]: *An example diagram of the inner design of the Airbus E-FanX.*

Carbon Capture (Climeworks)

We have decided to use a carbon capture technique from Climeworks. There are 2 phases of carbon capture; in the first phase the air is caught in a filter with a plant that is chemically bonded to the filter. When CO2 passes through the filter the CO2 stays on the filter and the outlet lets air without CO2 out. The second phase of the carbon capture technique involves heating the filter to about 100*C which concentrates the CO2 which then can be removed from the filter into a container in which the CO2 will be collected. We intend on using carbon capture for both while we are building the city as well as while the city is running to both absorb the carbon being produced by the sea travel, as well as the aircraft that is out of our control and of course to improve the air that makes it way towards the city from other areas, the carbon capture system that we would use would be a system similar to the Climeworks as currently it seems to be the most efficient at absorbing CO2 as well as using the least amount of land, at maximum intake the best model will absorb around 4920 KG a day which will certainly help remove any excess carbon dioxide that may still be polluting the city. This carbon dioxide can then be used in the production of other products such as carbonated soft drinks as well as recycling the carbon dioxide into biofuel or plant production facilities.

Figure [22]: *An image displaying the Climeworks Carbon Capture device.*

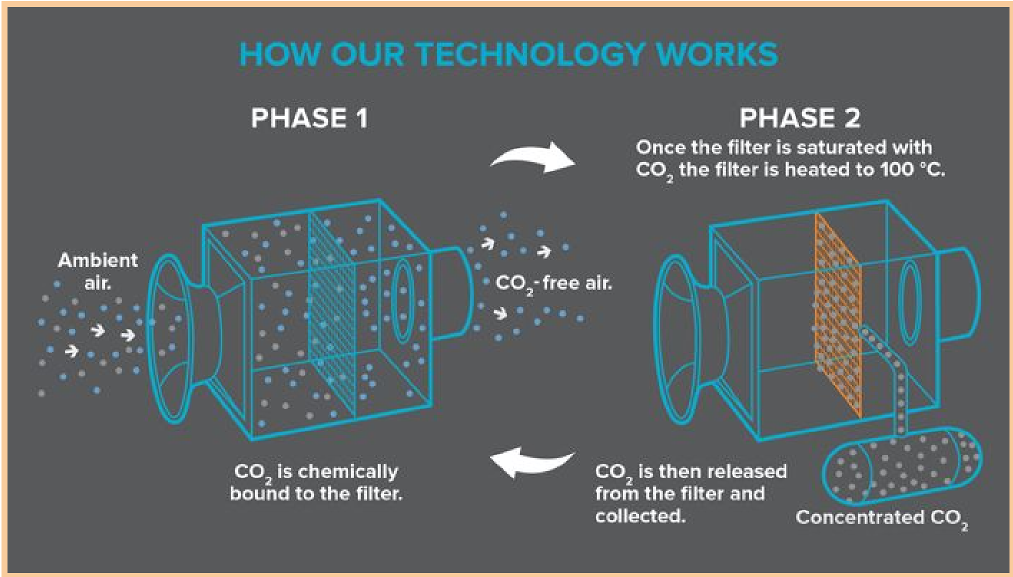

Figure [23]: *A diagram showing how the Climeworks Carbon Capture functions.*

Energy Requirement Analysis - Transport:

Autonomous Electric Car – The Tesla Model S would require **75 kWh** to charge completely from empty to full. However due to onboard protection built in to Teslas. It is impossible to fully discharge the vehicle battery therefore it would likely be slightly under the valueof **75 kWh**. However we will use the original value to ensure it will be fully charged. Elon Musk announced that the average distance a Tesla Model S of **75 kWh** capacity would last approximately 304 miles on a single charge. This is over 15 times the amount of miles required to travel the length of the city meaning that a single charge will be more than enough for most journeys. Most people won't travel this distance in a single day so assuming that car owners charge these vehicles a minimum of 4 times a month on average. It would result in an annual energy cost of **75 * 48 = 3600 Kwh per vehicle.** A total of 1 car per household we would require **2412 gWh**.

Autonomous Electric Bus – The Proterra Catalyst 40-foot is rated to have an energy level between **220** and **330 kWh** Therefore we will take the highest value of 330 to ensure full charge. This charge is estimated to last between 136 and 193 miles. Which is more than enough for the average bus journey routes in the area. The routes will most likely be able to complete multiple times before needing recharging. **1.29 Billion Miles** were travelled by bus in England during 2014/15. This divided by the total population and multiplied by 2,000,000 gives us a total of 396,252,495.7763784 Miles per year. Taking an average value of 150 miles per charge means we will need to charge the buses a total of 2,641,684 times. Which will result in an energy requirement of **871,755,720 kWh** which is equal to **871.75572 gWh** per year for all buses.

Maglev Train – The Transrapid form of maglev trains are stated to consume energy based upon the speed per hour the train is travelling due to this we will use the value of a Transrapid maglev train travelling at 350 kmh. It is said that this speed would require 47 watt hours per kilometer. There is **24.38** kilometers between Southampton and Portsmouth therefore a maglev train operating between these two areas would use **1,145.86 Watt Hours** of energy, which is equal to **1.14586 kWh.** This trip would take around 14 and a half minutes, allowing it to be completed 99 times in a single day. Therefore the total energy that could be used in a day would be **113.44014 kWh.** It is likely that we will have two trains operating this route to maximise transport availability. This will result in a maximum of **226.88028 kWh per day.** This would equal a maximum of **82,811.3022 kWh per year** for both vehicles.

Hybrid Plane - Unfortunately, Airbus have not announced any official energy requirements for the E-FanX. Therefore we will base our requirements off of the original model of the E-Fan X. The Bae 146, this plane is estimated to have used **856 US Gallons** of fuel per block hour. This is equivalent to **36.4 MJ/litre of fue**l. **856 gallons in litres is 3891.45**. Therefore **36.4 * 3891.45 = 141,648.78 MJ per block hour.** Using an average of 10 hours of flight per day this plane would require **1,416,487.80 MJ** per day. We do not know how many aircraft we will need however we will use the value of 10 for this calculation, more could be added if needed at a later date. This gives us a total annual energy requirement of **5,170,180,470 MJ** for all planes in a year which is equal to **1,436.1612416667 gWh.**

Water Transport - It is recorded that in 2015, water transport accounted for a total of 1.2 % of the total transport energy consumption. Therefore we can directly work out using our previous energy requirements that water transport should consume **19558.37 / 100 * 1.2 = 234.70044 gWh annually**. This value allows us to work out the average energy consumption per day, these values should be suitable as we will not be changing water transport at all.

Carbon Capture - The whole structure that captures carbon requires a low supply of heat to keep it running. The heat comes from burning waste which runs the air capture. This provides the majority of the energy which the air capture requires. There is no reference to how much the machine needs energy in total but the climeworks website states "*The majority of the energy required to run the direct air capture plant comes from low-grade/waste heat.*"Therefore we can assume that with some small modification the small amount of energy can be generated from a renewable source (such as a solar panel) that will be directly connected to the air capture machine.

Total:

Transport Solution	Energy per vehicle required annually	Energy required for total amount of vehicles annually	Notes
Autonomous Electric Car	3600 kWh	2412 gWh	Charging once a week. With one car for every house.
Autonomous Electric Bus	240,900 kWh	871.76 gWh	Charge on average every 150 miles.
Maglev Train	41,406 kWh	0.0828 gWh	N/A
Hybrid Plane	514018.047 GJ = 142,782.790 mWh Total 107,087.0925 mWh Fuel 35,695.6975 mWh Electric	1,436.16 gWh Total 1,077.12 gWh Fuel 359.04 gWh Electric	3/4 Energy required is fulfilled by fossil fuels.
Water Transport	N/A	235 gWh	All energy required from fossil fuels.
Carbon Capture	N/A	N/A	Negligible energy required
Total Annual Energy Consumption	378.096 gWh 36.009 gWh Electric	4954.99 gWh Total 3,877.88 gWh Electric	Required Fossil Fuel energy will be purchased. [See Costs]

General

Availability Of Technology:

Electric Autonomous Car:

In our current world companies have developed cars which can drive themselves. Our electric autonomous cars will be Tesla's cars and/or other companies which will provide them. One of the company is Tesla which all ready have the technology and programmes to run cars which can drive themselves. The only problem now is the law which doesn't allow the cars to drive themselves due to insurance issues and problems that can come up when there is an accident involving an autonomous car because at that moment it's not really clear who to blame for the accident. After a couple months or years the government will probably create laws regarding insurance and accidents so that we will be able to use those vehicles in our project.

Electric Autonomous Bus:

On May the 2nd 2017, Bus manufacturer Proterra announced they were working on a fully autonomous electric bus in collaboration with the university of Nevada. There is no announced release date for the bus however we believe it will be available within the next 10 years as work has already begun on creating this. In the meantime we planned to use a previous model of Proterra buses, the Proterra Ecoride Be35 which is a fully electric bus that has already been developed.

Maglev Train:

The first idea of a maglev train was developed in 1959, however since then this technology has been widely developed and tested in many different areas including the USA, Germany, Japan, United Kingdom and South Korea. There is currently six operational maglev systems within the world however the most known being the Shanghai Maglev train. As well as this, there are currently 3 maglev systems in development and 12 that have been planned. Therefore the technology is definitely available to create this system within our city.

Hybrid Plane:

The E-Fan X was announced on the 28th of November 2017 by Airbus, Rolls-Royce and Siemens. The Hybrid Plane should be flying by 2020 allowing us to implement the transport system into our plan within the goal of the next 10 years. This technology may take a few years to be commercially available however this is still suitable as we have an extra 8 years after the plane flies to implement it into our city.

Carbon Capture:

Climeworks Carbon Capture was released in 2014 and is being used across the world in places such as Hellisheidi, Iceland. The project in Iceland features placing the carbon capture device on one of the largest geothermal plants. This is an ambitious task and therefore it's likely Climeworks would like to continue to show their device working by implementing them into cities across the world. This makes the technology likely to be very available to us.

Carbon Neutrality:

Carbon neutrality relates to the fact that the city (in this example) doesn't leave any effect on nature by not emitting any net carbon dioxide, leaving no 'carbon footprint' whilst keeping other greenhouse gases to a minimum too. In our project city we're doing this by using solutions of generating electricity which don't release any carbon dioxide or other greenhouse gases. The method we are using is solar panels which are using only the sun's energy and convert that into electricity which is then used in our city, This method has no net carbon output due to the lack of fossil fuels used.

Furthermore, we have tried hard to ensure our transport solutions are not producing any carbon. The electric bus and car which we are using is powered by electricity which is generated by our eco-friendly solutions. The maglev train is also using only electricity. Therefore our solutions are suiting the description of carbon neutrality that's stated above. The only exceptions include the Hybrid plane we are using and the continuation of normal sea transport as no viable replacements could be found however to combat this problem we will implement carbon capture machines which will remove up to **4920 KG of CO2** in a single day. This carbon will then be repurposed into useful products preventing net output of any carbon emissions that may come from planes and traditional sea transport. On the official Climeworks website they state that their technology requires 3,300 km2 of land to remove 8GT of CO2 a year. Therefore we can work out that a single kilometre of climeworks systems will remove **2,424,242,424.24 KG** of carbon dioxide.

Calculations:

Method Introduced	Output Carbon (Annually)
Solar Panels	0
Autonomous Electric Car	0
Autonomous Electric Bus	0
Maglev Train System	0
Hybrid Plane	1800 * 365 = 657,000 KG
Water Transport	2.4 MtCO2e = 2438512580 Kilograms / 242,495 * 212.44 = 2,136,281.62
Climeworks Systems	8000000000000 KG / 3,300 = -2,424,242,424.24 KG per KM^2 / 800 = -3,030,303.03 per 1250 m^2
Total	-237,021.41 KG

No Carbon Trading or Large Scale Deforestation:

Our city is not using carbon trading or large scale deforestation due to the fact that our energy is generated through carbon neutral methods. As well as this none of our energy generation or transport methods will require the use of large scale deforestation as the land is already available and we have no use for resources generated by that method.

Costs (Initial, Running & Total)

Initial cost estimation:

Initial Cost - Energy:

Distributed Solar Panels:

The average UK house roof has a size of 1041.947 square feet. By making the roof pitch at 45 degrees (taking in consideration values of 8.6 meters and 5.2 meters we can get a hypotenuse of 12.16 meters). This will mean that there will be 680.624 square feet on the roof. If we cover 70% of the roof we will cover 476.437 square feet of solar panels. As 1 square foot of solars costs £16.38, the total cost will be £7,804.03 per house. Assuming, we have 3 people per house, we will have to have 670,000 houses which will cost **£5,228,700,100**

New Solar Homes:

We have discovered that to build an average sized house (85 square metres), which is a near zero carbon dwelling home. It costs **£2525.25 per square foot**. So to fully build a near zero carbon dwelling house it would cost a total of **£214,646.46 GBP**. This means that for 670,000 homes we have to pay **£14,381,312,820 GBP.**

When compared to a standard build, at the same square meterage the near zero carbon dwelling is £106,866.46 more than the standard home. Meaning that the the near zero carbon dwelling is just under double the price to build compared to a standard home however, this a price worth paying due the fact that it is much better for the environment due to it being nearly a zero carbon dwelling. As well as the insulation and energy saving technologies that will be implemented into the homes. The new homes can easily be sold once built to remake the money spent on the

Centralised Solar Farm:

Landmead Solar Farm was announced to cost an average of **£37 million GBP**. Therefore we can assume our centralised solar farm will be close to this number however to be safe we will use a value of **£45 million GBP** to account for larger size or any differences in production.

Centralised Battery Storage:

The centralised battery storage system will consist of lithium-ion technology, a similar example of this design is the large Hornsdale Power Reserve developed by Tesla. This was reported to cost **$800 million AUD** which is equivalent to **£452,162,032.96 GBP.** However this value is likely to go down the longer time goes on as this technology becomes more commonly used.

Distributed Battery Storage:

The distributed battery storage will also be a system that consists of lithium-ion battery technology. This will resemble the Tesla Powerwall, the Powerwall and supporting hardware is advertised as being **£5,900 GBP** However this is a consumer price and if we were to produce something similar for commercial use we may be able to get a lower price per battery. However for this calculation we will take the existing Tesla value. Based on the commercial price with 670,000 homes this would cost us **£3,953,000,000**. If we only gain a 20% reduction in price it will cost us **£3,162,400,000**. This number would of course be lower due to the fact that commercial price is always less than 10% consumer price as well as this within 10 year the price of this technology will be less due to it being more efficient, more accessible as more companies will develop similar technology.

Distribution Systems:

The cost of building a distribution system is estimated to be an average of **$200,000 USD per mile.** This means that to span the entire city (81.85 m^2) it would cost **$16,370,000 USD** which is equal to **£11,730,742 GBP.**

Initial Cost - Transport:

Autonomous Electric Car:

The autonomous electric car we are using is based off of the Tesla Model S and 3. The Tesla Model 3 is estimated to have a cost of $**25,281.90 GBP** per vehicle. This provides us with a good guide price for the purchasing of these vehicles, however these prices are for consumers. If we bought these cars as a commercial project we may be able to get reduced prices. Furthermore, the plan is to buy these cars and the cars will be offered to residents of solent city at reduced rates. This allows us to implement new, efficient and carbon neutral vehicles whilst also earning back money spent. The UK Plug-in car grant provides a **£4,500** discount off of all electric vehicles purchased. This brings our value per vehicle to **20781.90 GBP.** We can resell these vehicles to willing citizens of the city at a reduced rate with an interest free loan to regain our expenses whilst also gaining in the long term, as citizens will pay back a total of **£25,000 GBP.** We estimate to have one car per household therefore we will buy a total of 670,000 vehicles which will cost a total of **£13,923,873,000 GBP.**

Autonomous Electric Bus:

The Proterra Catalyst is said to be **$20,697 USD** this equals **£14,638.99 GBP.** The Proterra company is aimed at governments and local councils therefore they offer a finance program where the bus can be bought for **£14,638.99 GBP** per year. During this finance program Proterra are responsible for the battery operation and maintenance of these buses which reduces the costs of running these buses. There is 2 million people in this city, however they won't all need to use buses at the same time therefore we plan on implementing a total of 100 buses to travel Solent City and the surrounding area, this will cost a total of **£1,463,899 GBP** as an initial cost for purchasing the buses.

Maglev Train:

The costs of building the Shanghai Maglev Train system came to a total of **$1.2 Billion USD.** This has been estimated to be around **$105 million per kilometre of track.** However that system was entirely suspended which would cause it to cost more, in our system we wouldn't necessarily need it to be suspended if we needed to reduce the cost . Furthermore, development of the Shanghai system was completed in 2003. Therefore we can assume that due to the years difference the technology would be cheaper to implement resulting in a reduced price per kilometre. As stated before the distance between Southampton and Portsmouth is **24.38 Km** therefore the costs of building a track between the two would cost at maximum **$2.56 Billion USD** which is equivalent to **£1.85 Billion GBP.** However this value is likely to be reduced due to advancements in technology.

Hybrid Plane:

The E-Fan X is still too early in development to have an announced price for the initial cost. Due to this we will base our costs off of a normal plane similar to E-Fan X. Although this will not be fully accurate it will provide us with a base idea for the budget we will require which could later be changed when costs have been announced. The E-Fan X is a modified version of the British Aerospace 146, therefore we will use the value of this place as a base. The plane was said to have cost **£11 Million GBP** per plane in 1981 however this will have likely decreased since technology has become more advanced since then. However using this value with a total of 10 planes within the city it will come to a total of **£110 Million GBP** initial cost.

Climeworks:

Climeworks have announced that their project of providing a system that can make the largest geothermal plant in Iceland carbon neutral will cost $23 million dollars. This is the only price estimate that can be found for large systems of climeworks initial costs. This sounds like a large amount however since it is one of the few efficient ways of carbon capture we feel it is worth the money. Furthermore, since the city would be built relying largely on Climeworks systems they may be willing to offer deals which could significantly reduce the initial costs of developing climeworks systems. For this project we will assume we can use one of these systems to more than negate the left over amount of carbon produced from boats and incoming planes. Therefore we can assume that the cost of this facility will be around **$23,000,000 USD** which is **£16,267,900 GBP .**

Running cost estimation:

Running Cost - Energy:

<u>**Distributed Solar Panels:**</u>

Distributed Solar Panels have no total running costs due to the fact that they become owned by the homeowner after purchase of the new homes. Furthermore, the panels are designed to be extra resistant resulting in less chance of breaking them meaning they shouldn't have to be repaired often.

<u>**Centralised Solar Farms:**</u>

Luckily, solar farms require minimal maintenance however due to the size of the site and the fact it will be the primary energy source of the city it will still have to be monitored to prevent damage and loss of energy. This maintenance is estimated to cost $7.50 a year per kw in use. This would result in us spending a total of **$345,000 USD** annually per 46MW system. Our system is planned to use 196 of these systems and will span a much larger area which will cause the cost to be a total of **$67,620,000 USD** which is equal to **£48,442,663.66 GBP.**

<u>**Extra Fossil based Fuels For Hybrid Plane and Water Transport:**</u>

Kerosene is a fuel often used in aircrafts, our hybrid plane uses this fuel to fly as well as using electricity a single plane will require 107087.0925 mWh for a year of flight. Kerosene has an energy content of 46.2 MJ/kg and costs an average of 29p per litre therefore if we complete the following calculation we get the total amount of kilograms of kerosene that are required, 107087.0925 / 0.01283333 = **8344450.933623619 KG** This is followed by calculating the price of a full years worth of fuel, **8344451 KG * 0.29 = £2,419,890.79 GBP** per plane. Since we have 10 planes it will cost **£24,198,907.9 GBP** for total fuel per year.

Furthermore, we will need diesel to fuel the ships leaving the city docks, diesel oil has an energy content of 48 MJ/kg and costs 124.4p per litre. 235 gWh / 0.0000133333333333 = **17,625,000.00044063 KG** This provides us with the total KG of diesel oil we require to run all of the sea transport of Solent City for a year. **17,625,000.00044063 * 124.4 = 2,192,550,000.054814p** which is equal to **£21,925,500.00 GBP**

<u>Centralised Battery Storage:</u>

Finding the maintenance costs of centralised battery storage is difficult, after being unable to locate an exact value we have decided to use the values provided by an investigation into battery storage facilities, this document stated that the fixed cost of maintenance of a battery storage facility is **$267.40 USD** which is equivalent to **£191.61 GBP per year.**

<u>Distributed Battery Storage:</u>

The Tesla powerpacks don't have any running costs due to the fact that they do not need maintenance. Therefore we will use the value of zero.

<u>Distribution Systems:</u>

Distribution systems will not require large amounts of maintenance however will still need fixing if they break, unfortunately we have been unable to find specific values for the maintenance of this system however it is likely to be very low and therefore should not significantly affect the costs.

Running Cost - Transport:

Autonomous Electric Car:

The electric car will have no maintenance costs as once we have sold them to the citizens within the city they are no longer owned by us therefore there will be nothing to pay.

Autonomous Electric Bus:

Proterra have stated that the yearly running costs of their bus costs **£14,626.96 GBP.** This will be multiplied by 100 as this is the amount of buses we plan to buy however the running costs will most likely be reduced due to the larger amount of buses we will own in this city. This comes to a total of **£1,462,696** per year for running costs of the electric buses.

Maglev Train:

Due to the technology used within maglev trains there is a very low maintenance cost for the maglev train as they do not need to have regular check ups or repairs. This is due to the fact that the train is suspended using the gravitational field which means there is no wear or damage which would be caused by a traditional trains wheels. Since the train is causing no forces to act upon the rail it won't degrade, unlike traditional trains. Therefore the maintenance costs will be negligible compared to other transport methods.

Hybrid Plane:

Sadly, due to the hybrid plane's new development it is impossible to find an official value of the running costs of the E-Fan X. Therefore we will base our values off of the costs of a normal plane however theoretically the hybrid plane should be cheaper to run since it is partially electric. For a base idea of the maintenance costs we have used the cost of running the British Aerospace 146 which is an earlier model of the E-Fan X. The Bae 146 is recorded to have a maintenance cost of **$2,585.00 USD per hour.** Which is equivalent to **£1,859.87 GBP per hour.** This means a 10 hour flight would cost **£18,598.70 GB.** Using an average of 10 hour flights this would result in an annual running fee of **£6,788,525 GBP** per plane, since we are planning to use 10 planes we will have a total of **£67,885,250 GBP** running costs for all planes.

Climeworks:

Currently Climeworks in their Iceland facility estimate that the treatment of a **ton of CO2** costs **£424.38 GBP**. The system we plan on using will be able to treat a total of **3340.337 Tons** annually. This would result in a running cost of **£1,417,572.22 GBP** However Climeworks have stated that they aim to bring this value down to **$100 USD** per ton of CO2 in the near future. Which would result in an overall running cost of **£239,468.76 GBP**, a substantial decrease.

Overall cost estimation:

Total Initial Cost		Total Running Cost		Overall Cost*		
Energy	Transport	Energy	Transport	Energy	Transport	Total
£24,071,905, 694.96 GBP	£15,901,604, 799 GBP	£94,567,263. 17 GBP	£70,765,518. 20 GBP	£24,166,472, 958.13 GBP	£15,972,370, 317.2 GBP	£40,138,848, 275.33 GBP

* Overall cost consists of initial cost and one year of running costs.

Implementation

To begin implementation of our project we are going to build our solar farm and battery system so we can begin energy generation from the earliest point, this will give us a backup store of energy prepared for when the city is fully running. This will mean that once the city is built we will be able to transition straight into renewable energy. The first step is building the batteries that will be used for energy storage however whilst this is happening it would be useful to begin production on the solar farm itself. This would cost a total of **£497,162,032.96 GBP** for full development. However once these are both up and running we can begin storing electricity for future use and ultimately saving money in the long term.

After this, we can begin implementing our carbon capture system, this will remove any excess carbon dioxide from the air in our city. This will minimise effects from the building of our systems and city to begin whilst also being used to remove excess carbon produced by planes and sea transport. This will cost a total of **£16,267,900 GBP** as initial investment, this is necessary though as it is the only method that can effectively and efficiently remove carbon dioxide from the air.

Once that has been completed, we will start building our houses and all of the solar roofs. This has to be combined with the distributed batteries which will store the electricity produced from the solar roofs. This will mean that all of the houses will be carbon neutral and self-sustainable now meaning all of the city can now be powered from solar power. The total cost of building the houses and the roofs will come to a total of **£20,079,874,952.96 GBP** however again this will be worth it as we will be saving money in the long term from new insulation and solar energy.

During the building of the houses we will need to start buying all of the Tesla vehicles, due to the £5,000 reduction on electric cars we will have a reduced price on purchasing all the vehicles. Once we have acquired the vehicles which will cost **£13,923,873,000 GBP** they will be stored until people begin living in the city, every household will be offered a tesla as a method of transport if they take this offer they will gain the Tesla however must pay us a reduced rate per year or month that will equate to the original price of the Tesla. This will make these electric vehicles more accessible for all members of the city whilst costing us nothing in the long term as we will re earn all money spent given time.

We will also need to begin construction of the maglev system from current Southampton to Portsmouth areas we discovered this would cost a total of **£1.85 Billion GBP** however requires very little maintenance, once this has been completed we will have an extremely fast method of public transportation across the city taking only 14 and a half minutes either way. Whilst this is happening we should aim to purchase the total of 100 Proterra Electric Buses, this will cost a total of **£1,463,899 GBP** however we will be leasing these buses to local bus companies such as Bluestar, they will be required to use these buses in the area and once again will be able to own the buses at a reduced rate. This will encourage the transition to all electric vehicles and also cost us very little in the long term since we are earning the money back.

Sea transport will continue the way it always has however now with the addition of carbon capture in the city however we should add the hybrid planes to local airports. We stated we would buy a total of 10 Airbus E-Fan X's which would cost a total of **£110 Million GBP** however again we will lease these vehicles to local airports at reduced rates so eventually we will regain the money spent whilst implementing this new electric system.

Once this has all be completed the city should be fully setup and fully functional, we should have enough energy stored in the batteries to provide energy in the event of any downtime on our solar systems whilst also actively removing carbon from the city making it not only carbon neutral but also carbon negative. As well as this we will have carbon neutral electric transport systems implemented which will fully work, allowing us to begin having residents move into the city.This will have cost us a total of **£40,138,848,275.33 GBP** however once we have earned back the money spent on vehicles the value will come down to **£26,103,511,376.33 GBP**. Majority of this money is spent on initial costs therefore once this is out of the way the city should be very cost-effective to run, only costing a total of **£165,332,781.37 GBP** per annual. This development will likely pave the way for the same transformations in other large cities, leading to a cleaner environment and a healthier future.

More information

Appendices:

Information:	Link:
Population of the UK 2015	https://www.ons.gov.uk/peoplepopulationandcommunity/populationandmigration/populationestimates/timeseries/ukpop/pop
Energy Usage of the UK by Sector (2015)	http://webarchive.nationalarchives.gov.uk/20170617165441/https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/586245/ECUK_Tables_2016.xlsx
Hospital Energy Consumption	https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=3&ved=0ahUKEwjMzI7To7rZAhXKJMAKHd44DusQFgg2MAI&url=https%3A%2F%2Fwww.cibse.org%2Fgetmedia%2Fa9ab0fc1-97ed-4048-b6b5-936116334bc4%2FECG72-Energy-Consumption-in-Hospitals-1999.pdf.aspx&usg=AOvVaw33PHzmcN_lLPe_h59jF8yH
LED Lights Efficiency	https://www.thegreenage.co.uk/article/cost-comparison-led-spotlight-versus-halogen-spotlight/
Valve Wrap Efficiency	https://partner.energyimpact.co.uk/technology/insulation-valve-and-pump-wrap/
Draught Proofing Efficiency	https://www.nia-uk.org/consumer/understanding-insulation/draught-proofing/
Cavity Wall Insulation Efficiency	https://www.thegreenage.co.uk/tech/cavity-wall-insulation/
Quantum Dot Solar Cell Research	http://science.sciencemag.org/content/334/6062/1530 https://pubs.acs.org/doi/abs/10.1021/jp806791s https://en.wikipedia.org/wiki/Quantum_dot_solar_cell
Fuel used by British Aerospace 146 Plane	https://www.icao.int/Meetings/AMC/MA/2001/Allpirg4

	/wp28app.pdf
Fuel (Kerosene) to Joule Equivalent	https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwjLpIPJvJvZAhUBDcAKHQj9Dp4QFggnMAA&url=https%3A%2F%2Fwww.ocean.washington.edu%2Fcourses%2Fenvir215%2Fenergynumbers.pdf&usg=AOvVaw2jyjwAxgimzVdheZM9Ry1Y
Average Bus Mileage (2015)	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/485296/annual-bus-statistics-year-ending-march-2015.pdf
Water Travel Energy Values	https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwiDqLSTuZvZAhVmDcAKHZg2CzcQFggnMAA&url=https%3A%2F%2Fwww.gov.uk%2Fgovernment%2Fuploads%2Fsystem%2Fuploads%2Fattachment_data%2Ffile%2F633503%2FECUK_2017.pdf&usg=AOvVaw2YR7GzRt9VmeXl2TQVzIJH
Carbon Output by Water Transport (2015)	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/604351/2015_Final_Emissions_data_tables.xlsx
Carbon Output by the British Aerospace 146	https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwiy2bTOyZvZAhVBIMAKHVhIDogQFggnMAA&url=http%3A%2F%2Fwww.ipcc-nggip.iges.or.jp%2Fpublic%2Fgp%2Fbgp%2F2_5_Aircraft.pdf&usg=AOvVaw2fP5SPhbOHkeykP6t6Wcnq
Tesla Technical Description	https://www.tesla.com/en_GB/models
E-FAN X Plane Technical Description	http://www.airbus.com/newsroom/press-releases/en/2017/11/airbus--rolls-royce--and-siemens-team-up-for-electric-future-par.html
Proterra Bus Technical Description	https://www.proterra.com/products/40-foot-catalyst/ https://www.proterra.com/products/
Maglev Train Technical Description	https://www.energy.gov/articles/how-maglev-works
Carbon capture Technical Description	http://www.climeworks.com/our-technology/
Maglev Train Energy Consumption	http://large.stanford.edu/courses/2010/ph240/ilonidis2/

Information on Home Build Costs	https://designfor-me.com/cost-planning/how-much-does-it-cost-to-build-a-house/
Maglev Train Initial Costs	https://www.quora.com/What-are-the-cost-differences-between-Maglev-and-conventional-high-speed-rail
Distribution System Initial Costs	https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=3&ved=0ahUKEwj6npywtrrZAhUCXMAKHX1vBq4QFgg2MAI&url=https%3A%2F%2Fenergy.gov%2Fepsa%2Fdownloads%2Felectricity-distribution-system-baseline-report&usg=AOvVaw0WljgQApyacLblGWedELdd
Maglev Train Maintenance Costs	https://www.google.co.uk/url?sa=t&rct=j&q=&esrc=s&source=web&cd=1&ved=0ahUKEwi4w-Xy16DZAhUqLsAKHQPwAFsQFggnMAA&url=https%3A%2F%2Fwww.isr.umd.edu%2F~austin%2Fenes489p%2Fprojects2011a%2FMaglevTrains-FinalReport.pdf&usg=AOvVaw3lGzeHGDXDYWiWN9WNk2j6
Solar Farm Maintenance Cost Estimates	http://www.power-technology.com/features/featuresolar-array-maintenance-why-are-costs-falling-4872202/
Centralised Battery Maintenance Costs	https://www.nrel.gov/docs/fy16osti/64987.pdf
Diesel Fuel Prices	http://www.theaa.com/driving-advice/driving-costs/fuel-prices

References:

Figure:	Website:
1	http://www.blottmatthews.com/
2	https://www.google.co.uk/maps then edited using Photoshop.
3	https://www.google.co.uk/url?sa=i&rct=j&q=&esrc=s&source=images&cd=&cad=rja&uact=8&ved=2ahUKEwjc_LSBybfZAhUDZVAKHUeHBhkQjhx6BAgAEAQ&url=http%3A%2F%2Fgreenenergyelectrical.com.au%2Fhybrid%2Fhybrid-solar-system%2F&psig=AOvVaw1skgZVV9TeCJ_bzozdjSho&ust=1519321799145720
4	https://www.theguardian.com/environment/2014/dec/19/uks-biggest-solar-farm-connects-to-national-grid
5	https://en.wikipedia.org/wiki/Solar_Settlement_at_Schlierberg
6	https://www.tesla.com/en_GB/solarroof
7	http://www.lancaster.ac.uk/gallery/quantum-dots/
8	*http://mbe.rcast.u-tokyo.ac.jp/index_eng.html*
9	https://hornsdalepowerreserve.com.au/
10	http://sustainable-nano.com/2013/10/15/how-do-lithium-ion-batteries-work/
11	https://www.tesla.com/en_GB/powerwall
12	https://www.google.co.uk/url?sa=i&rct=j&q=&esrc=s&source=images&cd=&cad=rja&uact=8&ved=2ahUKEwjPxtfUr7rZAhXJJsAKHctiB_kQjRx6BAgAEAY&url=https%3A%2F%2Fwww.electricityforum.com%2Felectrical-training%2Fpower-system-analysis-and-design&psig=AOvVaw3UfvoejdVOCEOT2kNEJpku&ust=1519417670277432
13	https://www.google.co.uk/url?sa=i&rct=j&q=&esrc=s&source=images&cd=&cad=rja&uact=8&ved=2ahUKEwinkuPQr7rZAhWEKcAKHZHyBIIQjRx6BAgAEAY&url=http%3A%2F%2Fenergyeducation.ca%2Fencyclopedia%2FTransformer&psig=AOvVaw3bWCrBIzWo1nbVQZusLbSy&ust=1519418092860589
14	https://www.tesla.com/en_GB/model3

15	http://sites.psu.edu/siowfa16/2016/09/15/are-autopilot-cars-like-the-tesla-model-s-safe/
16	https://cleantechnica.com/2017/11/26/san-jose-international-airport-buys-10-electric-catalyst-e2-transit-buses-proterra/
17	https://insideevs.com/pair-of-rapid-charge-electric-proterra-ecoride-b35-buses-enter-service-in-california/
18	https://en.wikipedia.org/wiki/Transrapid
19	https://www.energy.gov/articles/how-maglev-works
20	http://www.airbus.com/newsroom/press-releases/en/2017/11/airbus--rolls-royce--and-siemens-team-up-for-electric-future-par.html
21	http://www.airbus.com/newsroom/press-releases/en/2017/11/airbus--rolls-royce--and-siemens-team-up-for-electric-future-par.html#media-list-image-image-all_ml_0-2
22	https://www.fastcompany.com/40421871/this-machine-just-started-sucking-co2-out-of-the-air-to-save-us-from-climate-change
23	http://www.climeworks.com/our-technology/