Overview

- A topic that is constantly discussed is one on the climate change and the impact renewable energy can have.

- Current practices in electronics production and the e-waste resulting from electronics use represent a large carbon footprint to the environment.

- This report highlights the potential of Synthetic Biology as a renewable solution in electronic manufacturing and in energy production.

- Lack of transparency in the issues involving Synthetic Biology is a barrier that needs to be bridged in order to get public backing on these projects.

- The isolation between science and politics is one we have noticed to be a hindering factor in the growth of projects like the one we are proposing and we are aiming explore this avenue.

Background

Climate change

According to scientists, 2015 has been the year where the Earth experienced the hottest June and the first half of the year since records began. The discussion on climate change has been gaining momentum, with it being heavily discussed in the World Economic Forum and now the global community is anticipating for it to come to a peak in the upcoming UN Climate Change Conference.

Energy consumption is essential for social and economic development. However, it has been a challenge to strike a balance between reducing greenhouse gas emissions without sacrificing economic growth. Since approximately 1850, global use of fossil fuels (coal, oil and gas) has increased, dominating the energy supply, leading to a rapid growth in carbon dioxide (CO_2) emissions and in turn contributed to climate change[1]. Due to this, there is a pressing demand for sustainable and renewable methods in how we source our energy. This report looks into how Synthetic Biology can offer a greener solution in terms of electronics production and, energy supply to households and factories.

Electronic waste (e-waste)

The increasing trends in both electronics use and manufacturing contribute to a significant part of environmental footprint. Copper, silver, tin, aluminium and lead are widely used in the devices that most of us use every day. The main issues in current electronics fabrication are that many of these raw materials are outsourced and a large amount of waste goes to electronic waste (e-waste) landfills. E-waste is the fastest growing type of waste, where most of it is dumped in Africa and Asia as seen in Figure 1. In 2000, more than 4.6 million tonnes of e-

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waste ended up in US landfills[2]. The worry is, the chemicals given off when these electronic products are put in landfills, can filtrate into the land or being released into the atmosphere. These consequently impact the environment and the communities living nearby. Regulations have been put in place in some European countries to prevent the dumping of electronic waste in landfills. However, some countries or places like Hong Kong for example, still have an estimated 10-20% of discarded computers that go to the landfills. The heterogeneity in regulations being laid by different countries meant that these e-wastes are oftentimes being exported to developing countries where the rules and regulations on this matter are less stringent. To illustrate this point, at least 23,000 metric tonnes of undeclared e-waste was illegally shipped to India, the Far East, China and Africa from the UK alone in 2003[3].

Figure 1 thelivinglabiesd.wordpress.com ***Sustainable Waste | E-Waste. What is that? What are the issues?***[4]

Degradation of solid waste in landfills causes methane to be released, a gas that has 21 times more global-warming effect than carbon dioxide. Besides, both burning and transportation of waste also contribute to greenhouse gas emission. Therefore, sustainable practices in sourcing the raw materials and manufacturing of electronics are vital to mitigate these problems. Our project taps into the potential of Synthetic Biology in producing a renewable material that can be used in electronics production.

Current renewable energy technologies and their limitations

We have been looking at the current renewable sources of energy and evaluating the limitations they have. With this, we can then compare and contrast our new Synthetic biology technology to the current technologies and envisage how our technology could fit into the current regulatory framework for optimum impact on the society and environment.

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- Solar

Solar energy is produced when radiant light and heat from the Sun is channeled using a range of technologies such as solar heating, photovoltaic and solar thermal energy. It is heavily dependent on intensity and duration of sunlight available at the position that solar panels are located, therefore making it geographically limiting. The cost of apparatus and assembly is expensive as well as the cost of repairs. This year the Conservatives want to slash the support mechanisms for roof-top solar by up to 87%[5].

- Wind

Wind energy is produced when turbines convert kinetic energy from the wind into electrical energy. The main limitation is that no energy is produced when the wind is not blowing, making it an unreliable source of energy. It can take many months for wind turbines to provide enough energy to make them viable. The turbines themselves require a vast amount of metal therefore their sources are non-renewable. Due to large-scale construction of wind turbines on remote location, it could be a threat to wildlife nearby. Studies have been done to determine the effect of wind turbines on birds and animals and the evidence is clear that wind turbines are a threat to animals.

- Biofuel

Biofuel energy is sourced from living things or the waste they produce. Biofuels have a lower energy output than other energy sources and therefore require greater quantities to be consumed in order to produce the same energy level. There is also concern regarding the use of valuable crop-land to grow fuel crops, which could have an impact on the cost of food and could possibly lead to food shortages. The machinery required to produce the biofuel has a large carbon footprint as well as the smaller carbon footprint created by the combustion of the biofuel although it is considerable smaller than other fuel alternatives. The biofuel itself requires refinement and this in itself can be very costly.

- Nuclear-

Nuclear energy uses nuclear reactions to generate heat and is most frequently used in steam turbines to produce electricity in a nuclear power stations. The energy is stored at the center of the nucleus of an atom. The mostly talked about limitation of nuclear energy is the disasters that have happened in the past in Chernobyl or more recently Fukushima where there have been large scale nuclear accidents.

Whether nuclear energy is deemed as renewable is still controversial. Some have argued that the fact that uranium is present in a limited quantity, should qualify this energy source as non-renewable. Eutrophication, the ecosystems response to the addition of artificial substance to an aquatic system, is another result of radioactive wastes and reports say that radioactive wastes take almost 10,000 years to get back to the original form as the radioactivity naturally decays over time meaning the waste has to be isolated and confined in appropriate disposal facilities

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until it no longer poses a threat. Another practical limitation of using nuclear energy is that it needs a lot of investment to set up a nuclear power station. Nuclear power plants normally take 5-10 years to construct, as there are several legal formalities to be completed and the people who live nearby usually oppose it.

Due to all the limitations outlined above, we see Synthetic Biology as an attractive alternative to solve the energy crisis.

Use of Synthetic Biology for electronics manufacturing and renewable energy production

Synthetic biology is an emerging area of research that looks at the design and construction of novel artificial biological pathways, organisms or devices, or the redesign of existing natural biological systems. It is an interdisciplinary branch of biology, linking biotechnology, molecular biology, system biology and genetic engineering.

Our project this year focuses on using genetically modified *Escherichia coli (E.coli)* cells to produce nanowires. One of the applications of this technology is circuitry production. This technology can also be scaled up, where these modified *E.coli* cells are grown in a bioreactor, generating green energy to households and factories.

To make the protein conductive, electron carriers are bound to it thus kick-starting a fusion process which generates the nanowires. Electric current will able to flow through these wires consequently they will be able to replace the copper, other metals in electronics. Since *E.coli* cells and the nanowire are both organic materials, they can be deemed renewable and their waste will not contribute to greenhouse gas emission.

Another advantage of our system is that the bacteria cultured in the bioreactor can be fed with waste products resulted from food processing. Cellulose, which can be found after sugar processing, or whey protein from dairy products processing are two examples of the waste products that can be used. Reusing of waste products to generate energy is a sustainable solution, while also saving costs.

Limitations of our system

Risk of Genetically Modified organism (GMO) release into the environment. There is a possibility of engineering a kill switch in the system so that the bacteria die upon contact with environmental stimuli. The project has a chance of having low public acceptance as many may see the use of bacteria in a system that might impact their society extremely uncomfortable.

As the use of Synthetic Biology to solve an energy problem is a new trend, there have not been any rules and regulations in this area of research yet. In 2013 the Green Deal incentive scheme was introduced however, there has been a rapid decline in home insulation installation rates, following high rates encouraged by previous policies and as a result funding for this scheme

was cut in July 2015 for wind and solar [6], though perhaps funding could be redirected in order to develop technologies such as Synthetic Biology.

One limitation that was common in the energy sources mentioned earlier is the concern locals have regarding the aesthetics of the neighbourhood. With our energy system we face the same problem, as some people may not be happy with living in an area where there is a bioreactor nearby.

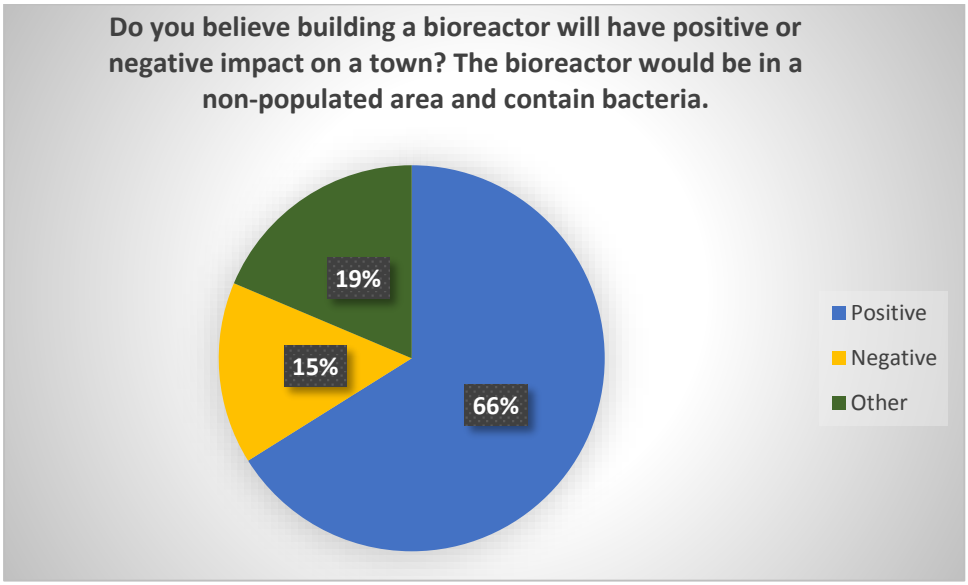

Figure 2 response on the Bioreactor

In a survey that we conducted, the conclusion can be made that a majority see the positive impact of having a bioreactor as shown in Figure 2, where those who chose *other* further emphasized the point that this would depend on where in the town and whether the locals view were strongly considered.

Environmental, political and societal aspects

- Environmental-

In 2014, UK greenhouse gas emissions were 36% lower than 1990 levels, meeting current targets [7]. Emission targets for 2025 may not be met without further Government action. Comparing our system with those mentioned above, the use of synthetic biology in energy production could cut down on emission of CO_2 and other pollutants. GMOs are organisms whose genetic material has been altered using genetic engineering techniques. Our project faces the risk of releasing GMOs into the environment and this falls within the scope of existing regulations and risk assessment framework. However, there is discussion as to whether existing regulations will be appropriate for potential future applications in this rapidly rising field. GMOs may be toxic to non-target organisms, bees and butterflies being the most talked-about examples currently. The Deliberate Release Directive (2001/18/EC), which covers a risk

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assessment on the release of a GMO to the environment[8]. Decisions on releases solely for research purposes are made at a national level following guidance from the Advisory Committee for Releases to the Environment. With the evidence shown in Box 1., we can conclude that our system will be safe and literature on "kill-switches" is what we need to ensure that the public can begin to accept the use of *E.coli* in energy production[9].

Box 1. A kill switch system is one which causes genetically modified organisms (GMOs) to die when it is turned on. Kill switch systems have become increasingly prominent in Synthetic Biology due to the public fear of the release of GMOs which could come into contact with organisms in the wild. There are a few ways in which the kill switch system can be activated. For example, a system can be engineered where the organism would die when it is starved of a specific amino acid that can only be found in the containment area. More recently, the emerging CRISPR technology has allowed accurate genome or DNA editing. This offered the alternative of creating a kill switch system in the DNA of the organism itself. Once the system is triggered, not only will the cell be destroyed, the 'modified part of the DNA' will also be deleted. So far researchers have only tested the DNA–removal system on *E.coli* concluding that the "kill-switch" successfully resulted in the death of the cells. Further development looks into the different stimuli which can trigger cell death. Although more researches are still to be carried out, the results are encouraging.

- Political-

Rising energy costs are starting to force the government to research alternatives to solve the energy crisis. There have been various political efforts to solve the renewable energy and climate change problems but they have not had a high impact. The latest renewable energy progress report published in 2015 stated that 25 EU countries are expected to meet their 2013/2014 interim renewable energy targets. These countries have already agreed on a new renewable energy target of at least 27% of final energy consumption in the EU as a whole by 2030[10].

Another example of how the energy market and the climate change issue are closely interconnected with politics is the recent happening where 886 Dutch citizens brought their government to court and the judge in The Hague ruled that the government has to reduce carbon emission by 25% in the next five years.

An intergovernmental initiative to combat climate change includes the Carbon Tax. This tax has been put in place to penalize countries which emit more carbon dioxide than the agreed quota and as a result, governments are looking into energy sources that will not have large carbon footprints. This tax has been implemented in response to commitments under the United Nations Framework Convention on Climate Change, though this changes between countries. Middle Eastern countries have no taxes on fossil fuel production as these areas depend on oil

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and gas production to aid their economy. In the UK, a tax was also put on in 2001, aiming to provide an incentive to increase energy efficiency and to reduce carbon emissions. The aim now is to simultaneously minimize energy costs, reduce pollution and promote economic growth, while maintaining reliable energy supplies.

- Societal-

There is always a need for cheaper energy, but people are becoming more environmental conscious. That being said, the society is still skeptical of new technologies due to the risks they posed. Nuclear energy is the cleanest form of energy but it has the highest risk, as seen in Figure 3, there is a small percentage of people that support nuclear energy production.

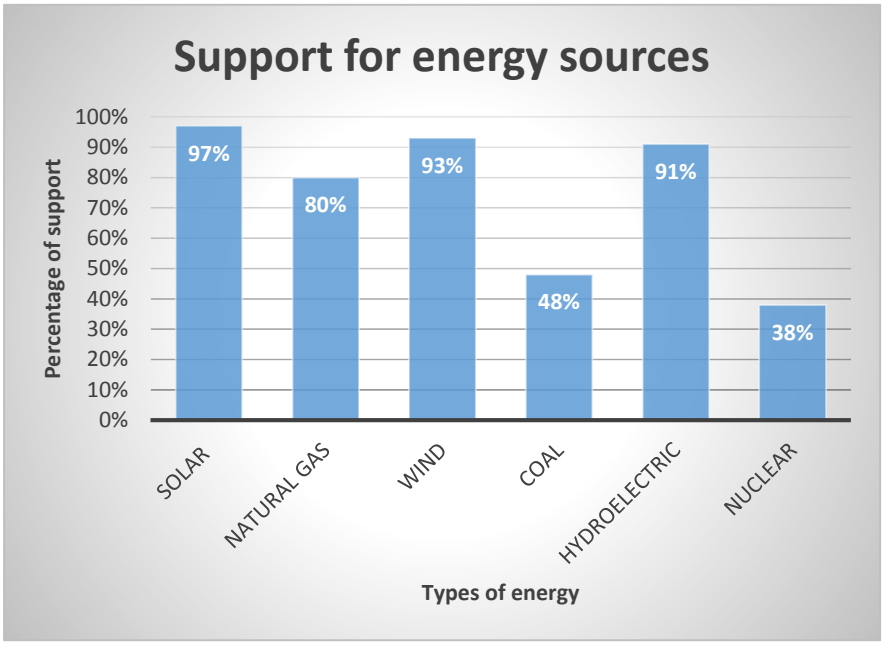

Figure 3 general support for different energy

Nuclear explosions in Fukushima and Chernobyl have caused the decrease in popularity for this energy source. In Germany, a coalition government formed after the 1998 federal elections had the phasing out of nuclear energy as a feature of its policy. With a new government in 2009, the phase-out was cancelled. This is reintroduced in 2011, three months after Fukushima, with eight reactors being shut down immediately. This is to be replaced with renewable energy. Other manifesto being laid out include cutting greenhouse-gas (GHG) emissions by 40% by 2020 to ensure that renewables contribute 80% of Germany's energy by 2050, and ensure energy consumption drops 20% by 2020 and 50% by 2050. In addition, the environmental levies was also increased from 2% of domestic dual fuel bills in 2004 to 7% in 2014, thus supporting the development of low carbon electricity generation technologies[11]. This also supported energy efficiency policies, which are helping to reduce bills for some homes.

We have taken steps to increase public awareness and probed into their perceptions on our project. Here, we outlined how we have stimulated a public dialogue on Synthetic Biology and our technology and how we have gauged the opinions of policymakers in order to assess how

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our technology can better solve the energy crisis.

- Stimulate a public dialogue

To find the most feasible solutions that can be accepted by the public yet practical in terms of science and technology, we have conducted a survey to see how much people know already about role synthetic biology can play in society. In early September, the Biosciences department at the University of Kent hosted a symposium. This was a chance to speak to the general public and inform them about our project. Here we could gather some data that could determine whether people would be in favour of not only using electronic devices that contained bacteria but also an energy source that is generated from bacteria grown in a bioreactor.

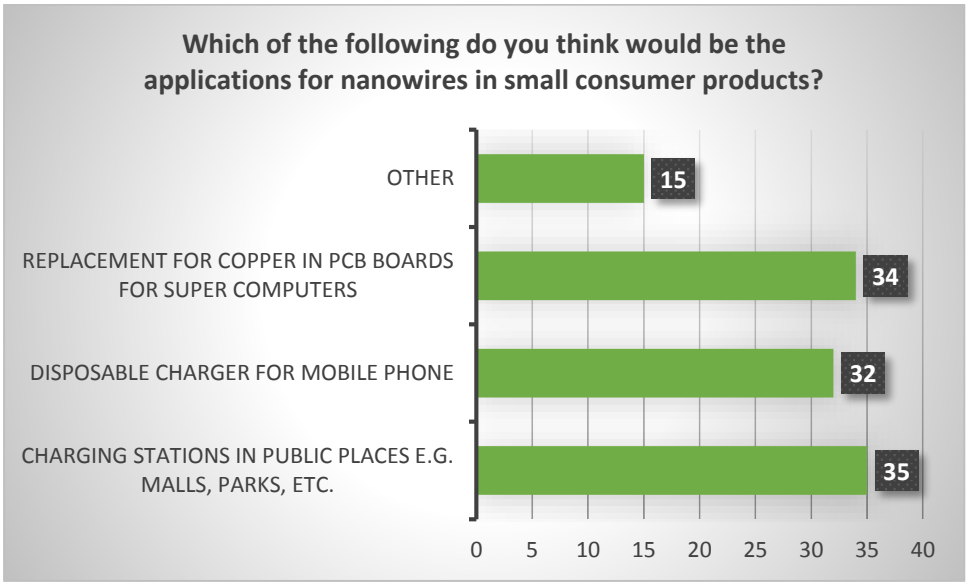

Figure 4 possible applications when looking at the electronic side of the project

During the symposium, where people from different backgrounds attended, we could gather the general perception regarding the use of synthetic biology. In Figure 4, the applications people associate with our electronic side of the project can be seen.

We interviewed a local city Councilor where one of the concerns he raised regarding our project was the use of *E.coli*, "…when I was reading, about *E.coli.* One of my questions was going to be how safe is it?" This is a general response we have received as we engaged in discussions on *E.coli* in innovative research and what people do not realize is that the strain of *E.coli* that is commonly used in our research is non-pathogenic, and thus will not cause any harm.

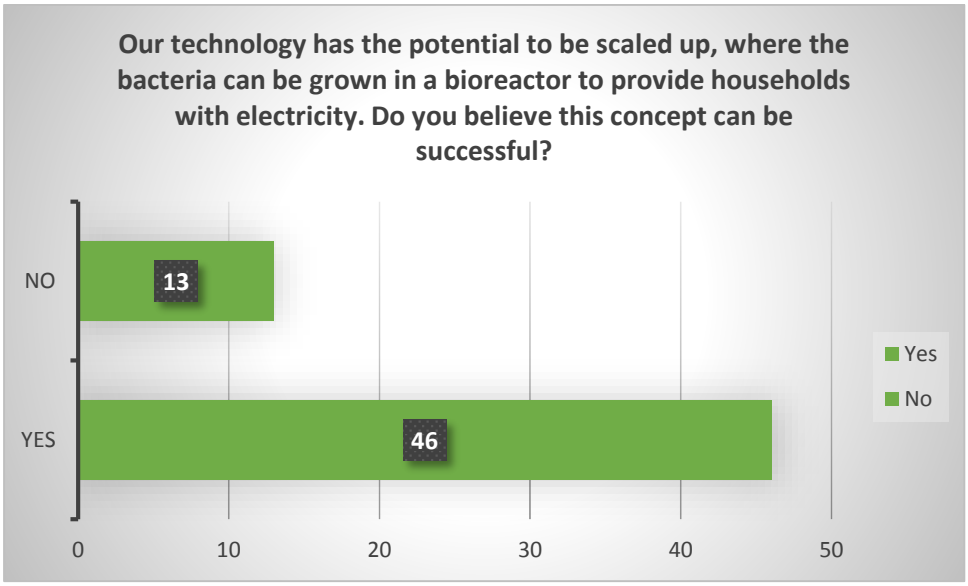

Figure 5 answer on the potential of our energy system

We wanted to gauge whether people appreciated the potential our project and results seen in Figure 5 showed that 78% of those questioned believed the concept would be successful. The positive response that we have received is very encouraging for the continuous pursuit of our research.

- Engagement of scientists with policy makers

We have seen the need of integrating Science and Politics, as having the right policies put in place would aid the movement of our project. There is a Climate Change conference happening in Paris this December and we contacted some politicians to find out what possible agendas their political parties would advocate for. An Italian Senator echoed what many would say when it comes to the discussion on climate change, "My party will advocate for anything that will promote sustainable developement." He had noticed growth in awareness on this topic, pointing out how in July he had lead a diplomatic mission in China and the authorities in Beijing had reiterated their engagement. He believed if this could head somewhere, there would definitely be a result in a historial change. In our research, we have spotted that the current law and lack of funding from the government are the two main issues inhibiting the emergence of new technology. Getting science and politics to work side by side, like the one we are proposing, will head in a positive direction. This is a critical time for Synthetic Biology to gain more prominence within the political framework.

- Transparency in the energy issues

In order for Synthetic Biology research to move forward, we need to draw public attention to ensure people know more about what is going on. Currently we see that some of the negative views people have on energy sources such as Nuclear are a result of the how we receive updates on the limitations. However the fact that it is the cleanest form of energy gets pushed aside and

it is this information that needs to be further publicized. When asked about implications and ethical dilemmas faced by synthetic biology and how to overcome this, the first response touched on how more information needs to be distributed. Quoting the leader of the Trentino Tyrolean Autonomist Party (PATT) of Italy, "The public needs to be engaged." He also emphasized on how the debate needs to go beyond all the emotional bias unlike how it too often happens in Italy when talking about themes such as synthetic biology. There is a need for transparency in the energy field, including risks, opportunities, possible developments and implications. And too often this has not been the case in Italy.

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