Scenario Analysis

We recognise that considering the potential environmental, ethical, and safety implications of our work in the wider world is of paramount importance.

It would likely take a number of years to translate the valuable science and initial design work we have carried out this summer into a final product, ready to implement in the real world. Hence, carrying out a detailed consideration of what this future world could look like, and what the position of our pod could be within it, is of the utmost importance. It will inform the way in which we proceed with aspects of our project prior to the iGEM giant jamboree, and will allow us to set forward a considered and responsible plan for the potential continuation of our project after iGEM 2017's conclusion. Such an approach will help to avoid major complications later down the line and maximise public benefit

Thus, in this scenario analysis, we have crafted detailed future scenarios relevant to the design and implementation of our project. The selection of our scenarios and means by which we developed and explored them are based on advice we received by consulting Australian Foresight Practitioner and Researcher, Maree Conway.

We first selected a handful of questions we wished to explore, then decided on two variables which would be key in defining where and how our project would be implemented, to form the axes of a simple matrix: level of NOx emissions from vehicles and level of NOx emissions from industry and/or power generations. Our four scenarios represent the four possible combination of high and low versions of each variable:

1. Low NOx emissions from vehicles, industry and power generation
2. High NOx emissions from vehicles, industry and power generation
3. Low NOx emissions from vehicles and high emissions from industry and power generation
4. High NOx emissions from vehicles and low emissions from industry and power generation

We then explored the possible technological, environmental, political, economic and socio-cultural factors that could have shaped each scenario. Here, we made use of extensive online research, encompassing a number of articles and particularly the National Grid's most recent annual 'Future Energy Scenarios' document, to ensure that scenarios were as detailed and rich, and as therefore realistic and useful, as possible. Our online research is outlined in footnotes, in case readers of this analysis wish to explore further the fascinating and pivotal issues raised below. We also incorporated experts' advice, for example on how current political and transport changes could develop - including the University of Bristol's Chair in Intelligent Transport Systems, Professor Eddie Wilson; Professor Nick Norman; Bristol City Council Cabinet Member for Energy, Waste and Regulatory Services, Fi Hance; and Avonmouth City Councillor Jo Sargeant. Our interactions with members of the public, for example at the Big Bang Fair and Avonmouth's Summerfest, also helped us to identify the public's needs and potential reaction to our project in varying contexts.

After this, we considered what the implications would be if our project was implemented into the real world in each scenario. We considered the questions we had selected. and formulated ideas for how we would approach each potential issue as effectively and responsibly as possible, seizing each potential opportunity which could ensure that our project has a positive impact on the world

We found that there was necessarily a degree of overlap between scenarios. This was highly useful for us to note, allowing us to identify particularly likely eventualities and potential issues and highlight key solutions which much be focused on now and as the project moves forwards - regarding design, human practices, etcetera

The year in which these scenarios are set is **2037**. Our product is unlikely to take this long to develop, however using a future setting this far from the present has allowed us to craft more varied and diverging scenarios, which will better enable us to plan for more distant and diverse futures.

How did the Scenario Analysis inform our project?

Project Plans – Informed by Scenario Analysis

Design:

Our analysis has shown that three main types of pods would be useful in our scenarios - industrial-scale pods, pods to be placed on street level, and personal pods to be placed in people's homes. Hence, we will lay an emphasis on adaptability and reflexiveness in our design efforts. In addition, we would consider, in future, perhaps having a different sub-team working on designing each of the three above types of pod, to ensure greater efficiency. Having laid the basic preparations for all eventualities, we would be able to focus more of our efforts on the types of pod which look to be more useful, depending on which scenario materialises.

Owing to the variety of different scales of pod that would be required across a number of our different scenarios, we would consider designing our bioreactors so that they could be slotted together into an array, making the scale and NOx metabolisation rate of the overall pod more easily customisable to different contexts.

We would lay a great emphasis on increasing the sensitivity of our NOx-metabolising technology, as this would make personal pods more viable, and this type of pod would be versatile and have a place, somewhere, in any future scenario. High sensitivities would also enable us to make smaller, more discreet street-level pods, should these be desired by local members of the public in consultations - meeting with members of the public at outreach events has indicated that some would prefer this.

To help make it self-sustaining and potentially add features to make more attractive part of environment, we will try to develop a fuel cell compartment, linked to the bacterial compartment of our pod, which will use the ammonia produced by our ammonia to create electricity. This could help give the pod the energy it needs to be self-sustaining (there is more on this in the Fuel Cell Design section of our wiki)

To prepare for the ultra-low airborne NOx scenario in which our pods would still be useful, but less so than in other scenarios, we would look into preparing an alternative design which would enable our pods to combat the eutrophication of water supplies.

Environmental:

Particularly in preparation for scenarios in which large industrial-scale pods, using greater volumes of materials, would be most useful, we would look to design our pod using as many materials which are recyclable as possible, to minimise wastage. To achieve this, we would look to the latest biomaterials research, to seek out low-wastage, durable and relatively inexpensive materials.

Dr. Tim Chatterton, Senior Research Fellow at the University of the West of England and Air Pollution expert, alerted us to the potential issues of producing ammonia from our pods - particularly with regards to the potential release of NOx gases back into the environment further along the life cycle, for example if the ammonia we produced is used as fertiliser. To prevent any risk of our pods' ammonia ultimately releasing NOx back into the environment, we aim to convert this ammonia into electricity using a fuel cell attached to our bacterial chamber - as mentioned above. This will release the harmless products of nitrogen and oxygen. (there is more on this in the Fuel Cell Design section of our wiki).

Safety:

Particularly in street or home pods, to minimise the chances of environmental release of any of our pods' contents, we would ensure to build our pods from a robust material. We would test our pods to breaking point in a controlled environment to ensure that everyday vandalism will not lead to any fundamental dangerous or wasteful damage

We would, in addition, of course, remove the possibility of released bacteria causing any significant harm by using a disabled, lab strain of E.coli which will immediately die outside of pod conditions

To help to preclude the theft and/ or general misuse of our pods or any of their components implemented on street level, we would ensure that they were robustly secured to the ground or whichever surface to which they were attached. We would test the strength of our connection to breaking point before implementing it to ensure that it would survive well under real world conditions

Should our pods be implemented in public spaces such as on street corners, to minimise the likelihood that members of the public attempt to vandalise our pods, we will design a public educational campaign to accompany their implementation. An aspect of this campaign will caution people not to touch the pods, as this could impair their functioning or lead to personal harm (although both possibilities would be unlikely). If necessary, each pod would have inscribed on it a warning that it should not be tampered with.

Public relations:

Professor James Ladyman, Philosopher of Science and former co-editor of the British Journal for the Philosophy of Science, stressed to us the vital importance of being transparent with members of the public about scientific advances which will affect their daily lives, from an early stage in the process. This is important to ensure our work is ethically sound but also to win public trust. Therefore, as, in certain scenarios, our pods would be useful on street-level, and would affect the aesthetics of areas of cities used by thousands of people, extended public consultations about what the pods should look like and where they should be would be essential. We have already set out to do this at public events such as the Big Bang Fair and Avonmouth's Summerfest, and through our conversations with a diverse range of members of the community, it was clear that the aesthetics of this pod and people's urban environment is something many feel strongly about. Therefore, we would continue to consult members of the public at every stage of the process as our project moved forward

Our conversations with members of the public from different areas of the city showed us that people's tastes where it comes to the style of pod to be implemented at street level vary greatly. Therefore, we would try to ensure that each area to receive a pod had its own set of consultations with locals, to ensure the aesthetics and location of our pod suited each community's needs as well as possible

We spoke to a local clay artist among others at Avonmouth's Summerfest, who suggested that we collaborate with local artists in helping to design pods which are attractive and locally relevant. As well as improving our pods' aesthetics and the likelihood that the public will accept them, this would potentially give us the opportunity to foster local creativity by using some of the investment capital we would have accumulated to pay local artists a small amount to collaborate with us. This would apply to street-level pods but also commercial personal pods, for which there could be a market in any of our future scenarios, and which would need to be aesthetically appealing for individuals to choose to purchase them

Bristol City Councillor Fi Hance and City Council Cabinet Member for Energy, Waste and Regulatory Services stressed to us the importance of designing our own public education campaign to help the wider public to understand what our plans are for their city and keep them updated at every stage, should we wish to have our pods implemented in public spaces in a scenario in which this would be useful. This is to help reduce the likelihood of tabloid newspapers producing scare headlines about our project, and of large swathes of the public being turned against our project because of this. Hence, we would design informative leaflets which could be widely distributed if we had sufficient funds, and we would use an up-to-date website and social media to keep people informed. We would also correspond with the local press to help us to keep control of the public narrative about our project and ensure that papers give us a fair representation.

Distribution:

For scenarios in which industrial-scale pods would be of use, we would lobby local and national government to introduce regulations, requiring companies wishing to build new NOx-emitting factories or power stations to help to offset their emissions by installing our pods

For scenarios in which street-level pods would be of use, we would liaise with City Councils about which areas to place them in - regardless of the extend to which Councils decide to fund our pods. As our discussions with Councillor Fi Hance and Avonmouth Councillor Jo Sergeant showed us, City Councils possess the necessary data and expertise to ensure the most effective and equitable distribution of public pods

In scenarios in which public pods would be useful, we would first seek funding for them from the Department for the Environment and Rural Affairs (DEFRA). As Councillor Fi Hance informed us, national government will be far more likely to possess the necessary funds to support at least part of our project's implementation

Should national government fail to fund public pods, we would seek funding or at least subsidies from local government

Should this fail, we would seek funding from private companies and individuals. This would be particularly likely to be necessary in one of the scenarios in which economic circumstances were poor and government finances would be particularly limited. Here, we would attempt to market our pods to individuals via crowdfunding initiatives as a charitable initiative - something which would benefit many, particularly the more medically vulnerable. We would seek to market our pods to large companies as means of improving their public image, by offering them sponsorship opportunities - their logos could be placed upon pods, which would be very much in the public eye. We would do all we could, here, to balance sponsorship requirements with what public consultations show are the desired aesthetics for our pod

In all scenarios, there is a place for personal, home-use pods. We would likely sell these as a commercial product, and would seek private investment. However, to ensure that not only the wealthy would be able to benefit from our personal pods, we would seek national and local government subsidies to help those economically more disadvantaged and living in areas of high NOx pollution to be able to purchase their own pod. We would try to ensure that costs are as low and pods are as affordable as possible, to minimise the amount of subsidy money which would be required here

In scenarios in which street pods would be useful, we would liaise with city waste disposal organisations such as Bristol Waste, to see whether the most basic maintenance of our pods could be added to their portfolios of functions.

The Analysis:

Scenario 1:

Low NO_x

Setting the Scene

- NOx levels **low in cities**
- NOx is **still produced from industrial processes** that require combustion, and pollutes the air around certain factories, but this is the case for fewer than in 2017 (some now use a catalytic techniques instead)
- Still **some NOx is produced by electricity generation**

- **Electric cars/buses** are now the primary modes of transport in cities
- Few petrol/diesel cars remain on UK roads and **hybrid cars are not allowed to engage their engines** when in city centres
- Very little electricity is generated in the UK using combustion processes
- All diesel trains replaced with **electric locomotives**
- All factories use **alternative techniques** instead of combustion when possible

What have been the driving factors?

Environmental

- Influential studies continue to be published demonstrating the negative health implications of NOx, raising awareness and solidifying pressure on policy-makers to create change
- Scientific community continues to produce increasingly convincing evidence of climate change and the importance of tackling it
- In the UK, the negative effects of climate change become more clearly visible, and shock environmental disasters
- Vivid images of the negative impacts of climate change globally appear on the news with increasing frequency - crop yields decrease in Africa, whilst historic buildings in Venice sustain significant damage as floods worsen rapidly year-on-year owing to rising sea levels

Technological

- Significant advances in electric car technologies, spearheaded by the Research and Development efforts of companies such as Tesla
- Rapid reduction in electric car prices – falling below those of equivalent petrol vehicles
- Incidence of electric car related infrastructure (such as charging points) has vastly increased
- The level of charge stored in electric car batteries increases significantly, from an average of 90-115 miles to an average of 200-250 miles
- Tesla's 'supercharger' technology reduces in price dramatically and relatively cheap household installations created, reducing charging times from 3-8 hours using a high-voltage output at home to 1.5 hours, and just 30 minutes at most charging points
- Less emission-intensive methods of manufacturing electric cars' lithium ion batteries are developed
- Solar panel efficiencies increase, whilst the price of wind and solar energy continues to fall

Low NO_x continued:

Political
- Significant pressure from UK national public opinion for the government to place a high priority on reducing harmful emissions, combined with prosperous economic circumstances, create both the will and means for policy-makers to create very rapid change
- Heavy congestion charges are initially placed on all diesel and petrol vehicles entering city centres, ultimately followed by an outright ban
- Increase in government grants to people purchasing electric and hybrid vehicles initially
- Outright ban on sale of new diesel and petrol cars well before the current target date of 2040

What are the implications?

Health
- NOx levels have a **minimal impact on health**
- Fewer instances of asthma and improvement in respiratory disease levels

Environment
- NOx-related **ozone damage lessened**
- Tropospheric ozone is reduced, reducing the damage to vegetation, crop-yields and forest growth.

Socio-cultural
- Clearer evidence of the damage caused by NOx pollution leads to increasingly vigorous grassroots campaigns against air pollution and the use of diesel and petrol cars in general
- Seen as increasingly socially unacceptable to own a petrol or diesel car
- Public opinion firmly in favour of rapid shift to low emissions, following increasingly clear evidence, close to home, of the potentially cataclysmic consequences of climate change

Economic
- Global economy gains strength, continuing to recover reasonably rapidly from the financial crash in 2008. Growth rates increase from 2016 rate of 2.438% to exceed its growth rate of 6.536% prior to the 1973 oil crisis. UK growth rate does likewise – increasing from a 2016 growth rate of 1.81% to surpass its 1973 peak of 6.52%.
- In the UK, unemployment remains low, and reduces from 4.5% (March 2017) to 2%.
- Increase in UK government revenue from taxation and public sector revenue
- National debt is significantly reduced, leaving the government with a small budget surplus
- Booming consumer market

How would we implement our pods into this scenario?

Uses for our project in this scenario:

- In factories that cannot use alternative techniques instead of combustion
- In cargo ships that still require diesel or biodiesel for high torque engines
- We would look to redesign the pods to tackle eutrophication of water
- We would research ways of increasing the sensitivity of our bioreactors so that people can create extra fresh air with personal pods for home/ garden use

What size of pod will be useful in this scenario?

- Pods are arranged in an array, so bioreactor can be custom-sized
- Large, variably sized pods for factories or smaller pods to be able to fit in people's homes, provided we can increase the bioreactor's sensitivity

Does it need to be stand-alone, self-sustaining system?

- This is less likely to be necessary in a supervised industrial situation, with dedicated maintenance teams, but would be highly useful for pods used in homes

Are there any potential environmental or health problems which could be caused by our pods in this scenario?

- We would use recyclable or recyclable plastics in manufacturing as well as investing in materials research for potential use of a recyclable and cost-effective biopolymer
- Where large, factory-scale pods are used, large volumes of ammonia will be produced so extra precautions should be taken to prevent leaks
- We could harness this ammonia via a fuel cell to produce electricity, water and nitrogen

How would the pods be financed?

- We would start campaigns to lobby councils to make regulations forcing companies with NOx-producing factories to mitigate emissions by implementing our pods
- Or we would sell pods as means for companies to improve their public image
- We would seek private investment to commercialise personal pods for home and garden use

Would the aesthetics of the pods be a significant issue?

- This is unlikely with industrial pods, as pods would be hidden away from public sight within factories. All efforts would be concentrated on achieving maximum efficiencies for minimum expense
- Personal pods would need to be aesthetically pleasing for people to choose to purchase these and place these within their homes and gardens
- We would therefore consult artists and interior design experts whilst designing our pods, to ensure aesthetics are taken into account. We would try to use local artists, to use our capital from private investment to promote creativity in our local area (whilst, at the same time ensuring costs are lower than had we consulted individuals from large companies or big-name artists)

Social inequality - will only some benefit?

- Industrial pods are most likely to help those who are less wealthy - living in more industrial areas with lower-priced housing
- If pods are made commercially available for private use, wealthier people would be better able to afford our pods and would therefore be able to obtain cleaner air at home than poorer people. To try to address this gap, we would, if necessary, press the government or council to subsidise the purchasing of our pods by those living in less well-off, more highly polluted areas

Summary of pods' utility

- Pods will be used to reduce NOx levels from low, virtually to zero
- Industrial pods will make a difference to health around industrial areas with significant NOx emissions
- Personal home-use pods would also help with reduction of NOx levels in houses near industrial areas or in the centres of cities which have still not reduced NOx levels to zero
- There will be some environmental benefit from reduction of industrial NOx emissions helping us to reach fully sustainable levels

Scenario 2:

Higher NO_x (Vehicles + Industry)

Setting the Scene

- **NOx levels higher** in cities than in 2017
- NOx **primarily in city centres** as direct effect of increased fuel cars on roads

- Increased populations in city centres, therefore decreasing traffic speed and **increasing car numbers**.
- Diesel and petrol car numbers not reduced
- Increased population leads to **higher industrial demand**, more factories opened to keep up
- Change in industry requires higher temperatures and more aggressive techniques leading to **higher NOx pollution per factory**
- Significant amount of NOx pollution produced from an increased number of factories involved in the production of electric cars, particularly those involved in producing lithium ion batteries

What have been the driving factors?

Environmental

- Globally, in most nations, the effects of climate change manifest themselves gradually, not directly affecting a great proportion of the world's population in a sufficiently detrimental way to generate greater action
- Impacts of climate change are felt disproportionately in developing African countries, whilst little clearly attributable impact is seen in the wealthier Western and Eastern nations who are the primary fossil fuel emitters. The affected African nations clamour for faster emissions reduction, but their urgings fall on deaf ears
- No notable shifts in understanding of the harmful effects of NOx pollution

Political

- Politically, investment in future sustainability projects is unviable with an economic downturn causing so much present strife in the UK
- Scarce government funds are necessarily directed away from investment in electric car technology and grants to purchasers of electric cars, and towards a struggling welfare system
- New congestion charges fiercely rejected so not implemented successfully

Economic

- A global economic downturn caused by another 'credit crunch' resulting from irresponsible lending hits the UK particularly hard at an uncertain time, as it transitions out of being a member of the European Union. This leads to rapid inflation and reduced consumer confidence and consumer spending.
- The UK national deficit increases dangerously once more, as the government struggles to cope with issues such as an ageing population. A quarter of the population is aged over 65 - which creates a far greater burden on the National Health Service and an unsustainable state pensions burden

Higher NO_x continued:

Technological

- Very slow development of electric car technology. Plummeting consumer spending suffocates the growth of electric car manufacturers and leaves them with less money to invest in Research and Development. Batteries continue to produce an average 90-115 mileage from one charge
- The UK government only fulfils part of its commitment to fund new electric car charging points and battery Research and Development, as well as expensive electric car grant programmes, owing to shortage of funds
- Increase in the cost of electric cars due to shortage in global supply of key battery materials - particularly cobalt
- Rapid advances in biodiesel and biopetrol technology - on the back of heavy investment from large oil companies - results in falling fuel prices, making diesel and petrol vehicles far more attractive to consumers than electric equivalents
- Owing to consumer pressure and the impossibility of introducing a sufficient number of electric vehicles to the roads, the UK government indefinitely delays the year by which new petrol and diesel vehicles can no longer be sold to the UK market
- Little improvement in diesel filter technology. An increased number of owners of diesel cars have their diesel particulate filters (DPVs) removed completely rather than having to pay the expensive £1,000 replacement cost - increasing their emissions fivefold

What are the implications?

Health:
NOx levels increased impact on health
More children and adults with asthma
Increased instances of respiratory disease
Hence, strain on healthcare system

Environmental implications of this scenario:
More NOx-related ozone damage
Tropospheric ozone is increased, increasing the damage to vegetation, crop-yields and forest growth, in and out of the city centre.

Socio-cultural

- Activists continue to campaign and point to notable cases of environmental degradation due to climate change, but in the majority of countries, including the UK, public opinion is firmly focused on the present economic difficulties, with relatively little thought for environmental sustainability
- In such a climate, electric cars are seen as an unnecessary and extravagant luxury
- In the general social climate, a self-centred and present-minded focus prevails, with little time or space allowed for expensive and forward-thinking altruism

How would we implement our pods into this scenario?

Uses for our project in this scenario:

- Our project is highly necessary in city centres where NOx-related issues are most prevalent
- Families can install personal pods to protect themselves in their homes

Our pods could be upscaled to be useful in industry.

What size of pod will be useful in this scenario?

- Pods are arranged in array, so the overall bioreactor can be custom sized
- Wide range of different forms of pods required - large for factories, smaller for street-level and potentially even smaller for commercial pods for private use in homes

Would it be useful if our pods were a stand-alone, self-sustaining system?

- Very useful for pods which are to be implemented on streets, so that less maintenance is required

Would any potential environmental or health problems be caused by our pods?

- We would use recyclable or recyclable plastics in manufacturing as well as investing in materials research for potential use of a recyclable and cost-effective biopolymer
- Where large, factory-scale pods are used, large volumes of ammonia will be produced so extra precautions should be taken to prevent leaks
- As far as street-level pods are concerned, there is a greater risk of pod damage and wear, so pods should be made of robust material and safety-checked on a regular basis. This will help to prevent environmental release of ammonia or bacteria

How would the pods be financed?

- We would start campaigns to lobby councils to make regulations forcing companies with NOx-producing factories to mitigate emissions by implementing our pods
- Could sell pods as means for companies to improve their public image. This would apply to industrial pods as well as street-level pods - for example, we would encourage supermarkets to fund pods outside their stores. To make this prospect more appealing, we would send the supermarkets pods with their branded logos upon them and a positive quote about the positive environmental impact the supermarket is having
- We would seek private investment to commercialise personal pods for home and garden use
- For street-level pods, we would seek funding or at least subsidy from either local governement or the national Department for the Environment, Food and Rural Affairs

Would the aesthetics of the pods be a significant issue?

- As pods implemented on the streets will impact the aesthetics of cities, many members of the public are likely to care about what the pods look like - disliking pods perceived to be unattractive
- We would hold discussions with councils looking to implement the pods to decide on whether their pods would be visible or hidden would be
- We would subsequently offer local artists the opportunity to collaborate with us to tailor pod designs to represent and display aspects important to local identity or cutting edge local design
- We would hold extended consultations open to members of the public to give their thoughts on design proposals

Social inequality - will only some benefit?

- Industrial pods are most likely to help those who are less wealthy - living in more industrial areas with lower-priced housing
- Pods implemented via council initiatives would likely lead to responsible placements
- We would liaise with councils to harness their expertise when deciding upon which areas to target with street-level or personal pods using limited funds from private sponsors
- If pods are made commercially available for private use, wealthier people would be better able to afford our pods and would therefore be able to obtain cleaner air at home than poorer people. To try to address this gap, we would, if necessary, press the government or council to subsidise the purchasing of our pods by those living in less well-off, more highly polluted areas

Summary of pods' utility

- Pods would be used to reduce NOx levels from high levels as part of an integrated approach with other technologies and initiatives
- Pods would have hugely beneficial impacts on health in this scenario
- Some environmental benefit, helping us to heal from damage

Scenario 3:

High NOx Emissions (Industry)
Low NOx Emissions (Vehicles)

Setting the Scene

- NOx levels are lower in city centres
- NOx levels are higher in Industrial and surrounding areas, and there is an increased number of factories/plants across the country

- More factories are opened
- There are higher NOx emissions per factory
- Congestion charges and Ultra-Low-Emission Vehicle initiatives lead to lower NOx levels in city centres
- There is a rise in electric car vehicle ownership
- A significant amount of NOx pollution is produced from an increased number of factories involved in the production of electric cars, particularly those involved in producing lithium ion batteries

What have been the driving factors?

Environmental

- Globally, in most nations, the effects of climate change manifest themselves gradually, not directly affecting a great proportion of the world's population in a sufficiently detrimentally to generate greater action
- However, after 2017, influential studies continue to be published demonstrating the negative health implications of NOx, raising awareness and solidifying pressure on policy-makers to create change

Socio-cultural

- Clearer evidence of the damage caused by NOx pollution leads to increasingly vigorous grassroots campaigns against air pollution and the use of diesel and petrol cars in general
- It is seen as increasingly socially unacceptable to own a petrol or diesel car
- Low public pressure for green energy solutions due to immediate fear of blackouts, and perceived slow pace of escalation of the negative impacts of global warming

Political

- There is significant pressure from UK national public opinion for the government to place a high priority on reducing harmful emissions
- Heavy congestion charges are initially placed on all diesel and petrol vehicles entering city centres, ultimately followed by an outright ban
- There is an increase in government grants to people purchasing electric and hybrid vehicles initiall
- Outright ban on sale of new diesel and petrol cars before the current target date of 2040
- Sudden, significantly increased demand for electricity, driven by electric vehicles, results in a scramble by UK policy-makers to produce as much electricity as possible to avoid politically damaging blackouts. Leaders initiate the construction of a new set of gas-fuelled power plants, as these can be brought online far more quickly than nuclear power stations. It is not possible to ensure that all of these plants incorporate a Carbon Capture and Storage (CCS) mechanism, resulting in significant levels of continued NOx pollution from power stations in the UK

Higher NO_x (Industry) Low NO_x (Vehicles) continued:

Technological

- There are significant and rapid advances in electric car technologies, spearheaded by the Research and Development efforts of companies such as Tesla
- There is a rapid reduction in electric car prices – falling slightly below those of equivalent petrol vehicles
- The level of charge stored in electric car batteries increases significantly over a short period, from an average of 90-115 miles to an average of 200-250 miles
- Tesla's 'supercharger' technology reduces in price dramatically and relatively cheap household installations were created, reducing charging times dramatically, from 3-8 hours using a high-voltage output at home in 2017 to 1.5 hours, and just 30 minutes at most charging points
- Changes in industry result in higher temperatures and more aggressive techniques being used, leading to higher NOx pollution per factory
- Developments in green energy production are slower than anticipated. Solar and wind energy efficiencies flatline and costs cease to reduce, remaining expensive
- There is an increase in UK nuclear energy generation
- Sudden, significantly increased demand for electricity, driven by electric vehicles, necessitates construction of a new set of gas-fuelled power plants, as these can be brought online far more quickly than nuclear power stations. It is not possible to ensure that all of these plants incorporate a Carbon Capture and Storage (CCS) mechanism, resulting in significant levels of continued NOx pollution from power stations in the UK

Economic

- An increased world population leads to higher industrial demand, with more factories opened to keep up
- The UK's current economic trajectory continues - very slow growth. The government's resources are relatively scarce as it continues to struggle to reduce the national debt, but it possesses enough resources to fulfil its current commitments to invest more than £800 million in driverless and clean technology and £246 million in battery technology research

What are the implications?

Health:

- As the increase in NOx levels aren't where populations are highest, negative health impacts of NOx have decreased on the whole
- There are decreased incidences of asthma and respiratory disease in general
- Health impacts are significantly worse for factory workers and people living near industry – implications towards house prices and socio-economic issues

Environmental:

- There is more NOx-related ozone damage on the whole, increased issues therefore with climate change etc.
- Tropospheric ozone is increased surrounding industry, and there is thus more NOx-related structural damage to vegetation and buildings that are near

How would we implement our pods into this scenario?

Uses for our project in this scenario:

- In factories, where they would be particularly useful owing to significantly increased emissions in cargo ships that still require diesel or biodiesel for high torque engines
- We would research ways of increasing the sensitivity of our bioreactors so that people can reduce NOx levels around their homes by purchasing personal pods for home/ garden use

What size of pod will be useful in this scenario?

- Large, variably sized pods would be useful for factories. Bioreactors could be arranged in an array, so the overall pod could be custom-sized and easily upscaled to different sizes
- Smaller pods would be useful for people's homes if we can increase the bioreactor's sensitivity

Does it need to be stand-alone, self-sustaining system?

- This is less likely to be necessary in a supervised industrial situation, with dedicated maintenance teams, but would be highly useful for pods used in homes, as less maintenance would be required in self-sustaining pods

Are there any potential environmental or health problems which could be caused by our pods in this scenario?

- Where large, factory-scale pods are used, large volumes of ammonia will be produced, so extra precautions should be taken to prevent leaks
- We could remove this ammonia by harnessing it via a fuel cell to produce electricity, water and nitrogen
- We would use recyclable plastics in manufacturing as well as investing in materials research for potential use of a recyclable and cost-effective biopolymer

How would the pods be financed?

- In this scenario, there is an urgent need to reduce NOx levels particularly in industrial areas surrounded by residential properties. It is likely that local councils or central government will be prepared to create legislation requiring those building new factories to undertake measures to reduce NOx levels around them - for example by using our pods
- We would seek private investment to commercialise personal pods for home and garden use. We would look to convince local and/or national government to subsidise or fully fund pods for those living in areas surrounding industry

Would the aesthetics of the pods be a significant issue?

- This is unlikely with industrial pods, as the pods would be hidden away from public sight. All efforts would be concentrated on achieving maximum efficiencies and safety levels for minimum expense
- Personal pods would need to be aesthetically pleasing for people to choose to purchase these and place them within their homes and gardens
- We would therefore consult artists and interior design experts whilst designing our pods, to ensure aesthetics are taken into account. We would try to use local artists, to ensure that our capital from private investment promotes creativity and a positive relationship between the arts and sciences in our local area (whilst, at the same time ensuring costs are lower than had we consulted individuals from large companies or big-name artists)

Social inequality - will only some benefit?

- Industrial pods are most likely to help those who are less wealthy - living in more industrial areas with lower-priced housing
- If pods were made commercially available for private use, wealthier people would be better able to afford our pods and would therefore be able to obtain cleaner air at home than less wealthy people. To try to address this gap, we would, if necessary, press the government or council to subsidise the purchasing of our pods by those living in less well-off, more highly polluted areas

Summary of pods' utility

- Industrial pods will make a difference to health around industrial areas with significant NOx emissions
- Personal home-use pods would also help with reduction of NOx levels in houses near industrial areas or in the centres of cities which have still not reduced NOx levels to zero
- There will be some environmental benefit from reduction of industrial NOx emissions, helping us to reach fully sustainable levels. This would most significantly benefit plant and wildlife surrounding industrial areas

Scenario 4:

Low NOx Emissions (Industry)
High NOx Emissions (Vehicles)

What have been the driving factors?

Socio-cultural

- Public opinion shifts firmly in favour of rapid shift to low carbon emissions, following increasingly clear evidence, close to home, of the potentially cataclysmic consequences of climate change
- Biofuels and hybrid vehicles are seen as the solution which will bring the most rapid reduction in CO2 emissions by a public disillusioned with the slow pace of improvement and expensiveness of electric vehicles

Setting the Scene

- NOx levels are higher in city centres
- NOx levels are lower in Industrial and surrounding areas

- Increased populations in city centres, therefore decreasing traffic speed and **increasing car numbers**.
- Diesel and petrol car numbers not reduced
- All factories use **alternative techniques** instead of combustion when possible

Political

- Public pressure in the UK results in limited government resources being prioritised on reducing CO2 emissions, through increased subsidies for renewable energy sources and fuel sources
- Policy-makers perceive that it will be impossible to generate enough electricity to fuel the increased demand from a greatly increased number of electric vehicles on the road, without scaling back their ambitions to dramatically reduce the quantity of fossil fuels burned to generate electricity. They therefore prioritise the latter, focusing more on encouraging low carbon biofuels (which still produce NOx emissions through combustion) than electric vehicles
- More stringent regulations are placed on industrial NOx emissions and building of new factories is limited

Environmental

- The international scientific community continues to produce increasingly convincing evidence of climate change and the importance of tackling it
- Alongside this, in the UK, the negative effects of climate change become more clearly visible, and shock environmental disasters occur – including heavy snow and socially and economically damaging flash floods in the winter months, as well as drought- and heat stroke-inducing heatwaves in the summers
- Alongside this, vivid images of the negative impacts of climate change globally appear on the news with increasing frequency - crop yields decrease in Africa, whilst historic buildings in Venice sustain significant damage as floods worsen rapidly year-on-year owing to rising sea levels
- There are no notable shifts in scientific understanding of the harmful effects of NOx pollution, as the environmental scientific community's attention and funding are concentrated almost exclusively on the problems caused by global warming

Lower NO_x (Industry) Higher NO_x (Vehicles) continued:

Technological

- Solar panel efficiencies increase rapidly, at an exponential rate, whilst the price of wind and solar energy continues to fall precipitously
- Electric car technology develops very slowly. Batteries continue to produce an average mileage of 90-115 miles/ charge
- The UK government only fulfils part of its commitment to fund new electric car charging points and battery Research and Development, as well as expensive electric car grant programmes, owing to shortage of funds
- There is an increase in the cost of electric cars due to shortage in global supply of key battery materials - particularly cobalt
- Rapid advances in biodiesel and biopetrol technology - on the back of heavy investment from large oil companies - results in falling fuel prices, making diesel and petrol vehicles far more attractive to consumers - and a government seeking low-carbon solutions - than electric equivalents
- Owing to consumer pressure and the impossibility of introducing a sufficient number of electric vehicles to the roads, the UK government indefinitely delays the year by which new petrol and diesel vehicles can no longer be sold to the UK market
- There is little improvement in diesel filter technology. In fact, an increased number of owners of ageing diesel cars have their diesel particulate filters (DPVs) removed completely rather than having to pay the expensive £1,000 replacement cost - increasing their emissions fivefold

What are the implications?

Economic

- The UK's current economic trajectory continues - very slow growth. The government's resources are relatively scarce as it continues to struggle to reduce the national debt
- Escalating negative impacts of global warming such as flooding produce economic damage across the globe including in vulnerable areas of the UK such as the Somerset Levels

Health:

- NOx levels have an increased impact on health in cities
- More children and adults have asthma
- There is an increased incidence of respiratory disease
- Hence, there is a greater strain on the national healthcare system

Environmental:

- Tropospheric ozone is increased in urban areas - particularly in city centres - resulting in more NOx-related damage to vegetation
- However, there is less environmental damage surrounding factories and power stations

How would we implement our pods into this scenario?

Uses for our project:

- The implementation of our pods would be particularly pertinent in city centres, where NOx-related health complications are most prevalent
- Individuals and families can install personal pods to protect themselves in their homes

What size of pod will be useful in this scenario?

- A wide range of different forms of pods would be required - large for factories, smaller for street-level and potentially even smaller for commercial pods for private use in homes. However, smaller street-level and personal pods would be most useful in this scenario
- Bioreactors could be arranged in an array, so the overall pod could be custom-sized and easily upscaled or downscaled to different sizes.

Would it be useful if our pods were self-sustaining, stand alone pods?

- This could be very useful for pods which are to be implemented on streets and in homes, so that less maintenance is required

Would any potential environmental or health problems be caused by our pods?

- As far as street-level pods are concerned, there is a greater risk of pod damage and wear, so pods should be made of a robust material and safety-checked on a regular basis. This will help to prevent environmental release of ammonia or bacteria
- Bacteria used will be a disabled, lab strain which will die when released from pod conditions

How would the pods be financed?

- We would sell pods as means for companies to improve their public image. For example, we would encourage supermarkets to fund placing pods outside their stores. To make this prospect more appealing, we would encourage supermarkets to fund pods outside their stores. To make this prospect more appealing, we would send the supermarkets pods with their branded logos upon them and a positive quote about the positive environmental impact the supermarket which would be clearly visible to members of the public passing by
- We would seek private investment to commercialise personal pods for home and garden use
- For street-level pods, we would seek funding or at least subsidy from either local government or the national Department for the Environment, Food and Rural Affairs

Would the aesthetics of the pods be a significant issue?

- As pods implemented on the streets will impact the aesthetics of cities, many members of the public are likely to care about what the pods look like - disliking pods perceived to be unattractive
- We would hold discussions with councils looking to implement the pods to decide on whether the pods would be discrete or clearly visible, and in the latter case, what the appearance should be
- We would subsequently offer local artists the opportunity to collaborate with us to tailor pod designs to represent and display aspects important to local identity or cutting edge local design
- We would hold consultations open to members of the public to give their thoughts on design proposals

Social inequality - will only some benefit?

- Pods implemented via council initiatives would likely lead to responsible placements
- If councils refuse to fully fund our pods, we would liaise with them to harness their expertise when deciding which areas to target with street-level/personal pods using funds from private sponsors
- If pods were made commercially available for private use, wealthier people would be better able to afford our pods and would therefore be able to obtain cleaner air at home than poorer people. To try to address this gap, we would, if necessary, press the government or council to subsidise the purchasing of our pods by those living in less well-off, more highly polluted areas

Summary of pods' utility

- Pods would be used to reduce NOx levels from high levels as part of an integrated approach with other technologies and initiatives
- Pods would have hugely beneficial impacts on health in this scenario, particularly that of people living in city centres
- Personal home-use pods would help with reduction of NOx levels in houses in the centres of cities which have still not reduced NOx levels to zero
- Street-level pods would also help reduce the detrimental environmental impacts of NOx emissions in parts of cities with busier roads

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