forum for the future
action for a sustainable world

friends of the earth
see things differently

BBSRC
bioscience for the future

Synthetic biology: a deliberation aid

Synthetic biology: a deliberation aid

This aid has been put together by Forum for the Future, Friends of the Earth (England, Wales and Northern Ireland) and the BBSRC. It aims to help individuals and groups interested in engaging with synthetic biology to consider a broad range of risks and opportunities and a variety of perspectives on them. We hope that it will stimulate dialogue and support the making of better-informed, sustainable decisions that address the challenges and embrace the opportunities that lie ahead.

Contents

Supporting materials

About this aid

The world is changing fast through man-made pressures such as climate change and biodiversity loss. Technology, and biotechnologies such as synthetic biology, may offer exciting potential solutions to the challenges that lie ahead. But they also carry with them risks, so robust decision-making is vital. This calls for open discussion and sharing of ideas, and a readiness to engage with the full spectrum of views.

This aid has been put together by Forum for the Future, the BBSRC and Friends of the Earth (England, Wales & Northern Ireland) to support that decision-making process. It has been designed to help individuals and groups interested in engaging with synthetic biology to base their decisions on wide considerations and experiences, by considering a broader range of questions than they might otherwise and engaging with a wide variety of different perspectives, such as those illustrated by the personas in Section 3 (see page 59). We have tried our best to avoid bias in the deliberative questions and, where it is unavoidable, to be clear about our sources.

We hope this aid will:

- Be of use to researchers, businesses, investors, policy-makers and NGOs in exploring the sustainability of potential or actual uses of synthetic biology.
- Help individuals and groups to better understand and empathise with alternative views on synthetic biology applications.

We would also like to see the current version – version 1.0, developed on a small budget within a limited timeframe – picked up and improved upon by others.

Please note that this aid is intended to complement, not replace, more comprehensive decision-making aids, such as the multi-criteria mapping tool developed by the Science Policy Research Unit at Sussex University (**http://www.multicriteriamapping.com/**).

What's in the aid

The main focus of the aid is a set of 14 questions (Section 2) designed to help you systematically explore the sustainability of a potential application of synthetic biology. The questions are complex, and interact with each other. It is important to consider any trade offs that you identify, for example where a potential application promises significant benefits in one area but there is a risk of negative impacts in another.

The resources in Section 1 and Section 3 provide background information that will help you to understand and engage fully with the questions, including:

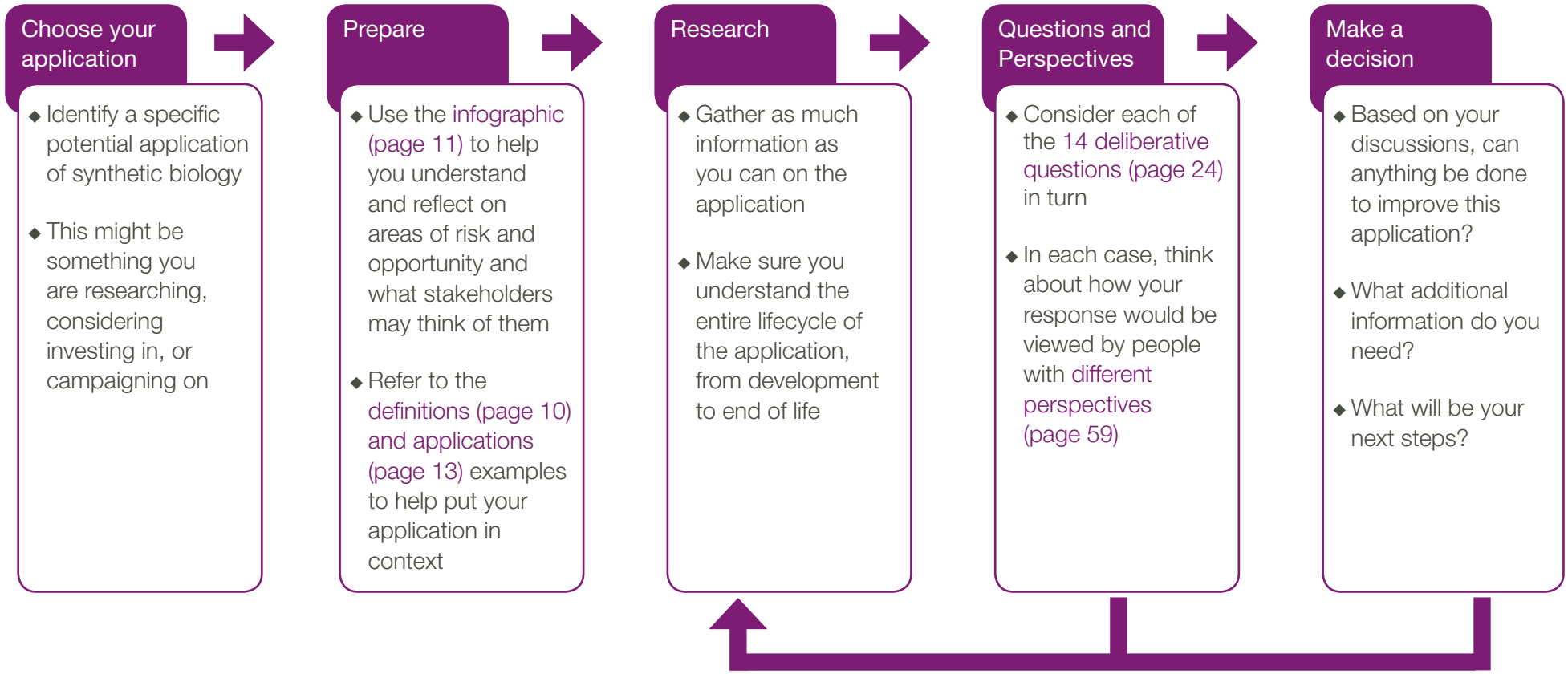
- Definitions of synthetic biology (page 10).
- Technology appraisal infographic (page 11): a graphic representation of the main factors that people use to assess synthetic biology and its applications. The areas covered in the infographic are explored in more detail in the questions.
- Applications (page 13): examples that illustrate what synthetic biology is, and show some of the ways in which it can be used.
- Further resources (page 56): a set of personas to help you explore different perspectives on and attitudes to synthetic biology, plus sources of further information.

What else you will need

To use the deliberative questions, you will need information on the specific application that you are considering. This can be challenging to find and verify in the current context, and to present in a way that does not create commercial or competitive risk and that is comprehensible to non-experts.

We strongly encourage greater transparency and the provision of more accessible information on synthetic biology applications in the future. We all have a role in making this happen. If you are developing an application, we invite you to share as much information as you can.

How to use these resources



This aid works best if you…

- Are open to learning something new, even if you are an expert
- Appreciate the importance of empathy and are open to the view that no perspective is right or wrong
- Consider the questions with others
- Use the links provided
- Take time to consider a range of different perspectives on synthetic biology and its applications
- Give honest and detailed responses to the questions
- Are open to the possibility that your responses may point to a different approach, and that this may not involve synthetic biology
- Record your responses so that you can refer to them in the future.

What is synthetic biology

Definitions of synthetic biology

One of the challenges faced by those trying to understand and engage with synthetic biology is the lack of any commonly agreed definition, and the widespread use of jargon. On the following page you will find a list of definitions from a range of stakeholders. Each one reflects in some way the perspective of the writer, often drawing attention to a particular area of concern or opportunity on the accompanying Infographic.

We are unlikely to arrive at a globally agreed definition soon. It is therefore essential that anyone exploring this area is aware of the lenses that people use when applying the term synthetic biology. The conversation is certainly more productive when you understand exactly what others mean when they use the term.

We have deliberately not given our own definition of synthetic biology, as we do not believe it would be useful. We believe it is more important to consider what is actually happening or proposed – rather than what it is called – and how it could contribute to a sustainable future.

Definitions of synthetic biology

Author of definition	Definition
Research Councils UK	The engineering of biology: the deliberate (re)design and construction of novel biological and biologically based parts, devices and systems to perform new functions for useful purposes, that draws on principles elucidated from biology and engineering.
David Drubin et. al	A variety of experimental approaches that either seek to modify or mimic biological systems.
ETC	Synthetic biology may be understood to involve various techniques of modern biotechnology that exercise control in the design, synthesis or redesign of new biological organisms, parts, devices and systems at the organismal, cellular or sub cellular level for applied purposes. Synthetic Biology is particularly associated with chemical synthesis of genetic sequences, genome editing techniques and an engineering-based approach to the construction of living organisms resulting in a range of products, living and non-living, and of differing characteristics
EU NEST (New and Emerging Science and Technology) Experts	The synthesis of complex, biologically based (or inspired) systems, which display functions that do not exist in nature. This engineering perspective may be applied at all levels of the hierarchy of biological structures – from individual molecules to whole cells, tissues and organisms.
European Commission	The application of science, technology and engineering to facilitate and accelerate the design, manufacture and/or modification of genetic materials in living organisms.
Friends of the Earth US	Synthetic biology, although still undefined, can be described as 'extreme genetic engineering,' and refers broadly to the use of biological engineering to design and construct new synthetic biological parts, devices and systems, and to redesign existing biological organisms.
Greenpeace UK	At its core, synthetic biology is engineering applied to biology to deliberately (re)design and construct biological systems. Put another way, tailored biological systems are produced for specific purposes using a great degree of manipulation.
UK Royal Society	An emerging area of research that can broadly be described as the design and construction of novel artificial biological pathways, organisms or devices, or the redesign of existing natural biological systems.
www.sytheticbiology.org	There are two parts: a) the design and construction of new biological parts, devices and systems; and b) the re-design of existing natural biological systems for useful purposes.

Technology appraisal infographic

People draw on a wide range of factors to assess and form opinions on synthetic biology and its applications. The infographic on the following page sets out those factors in a way that is clear and easy to understand. Each circle represents a factor – which may be positive or negative – that has been identified through dialogue or in articles and papers about synthetic biology.

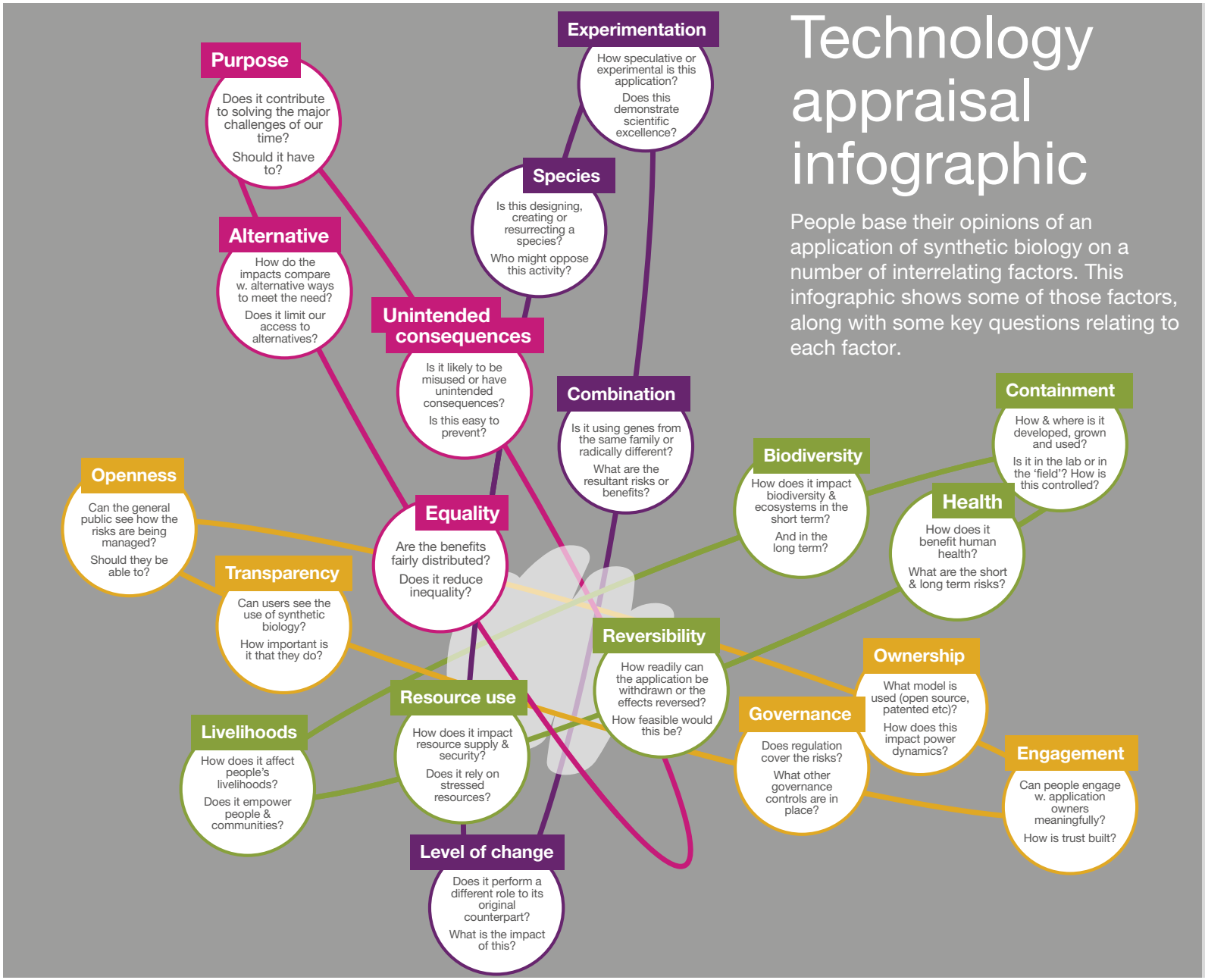
Use the infographic to familiarise yourself with these factors, to reflect upon your own responses and to think about how others might respond.

Some factors will weigh more heavily for some people than others. What one person dismisses as irrelevant, another will see as a very important consideration. There are many reasons for this including different world views, knowledge and values. This is inherently subjective and there will never be consensus on which factors matter most.

Similarly, an application will likely “rate” more positively against some factors than others. Use this infographic to identify and make explicit any trade-offs involved.

Technology appraisal infographic

People base their opinions of an application of synthetic biology on a number of interrelating factors. This infographic shows some of those factors, along with some key questions relating to each factor.



How can synthetic biology be used?

Applications of synthetic biology are being developed in many areas including food, medicine and household cleaning products to name just a few. In some, an organism is genetically altered to produce more of a product – for instance, oil – or an alternative product. In others, it is the organism itself that is the product, for instance a genetically altered mosquito. The most common organisms used in genetic alteration currently include yeast, algae and bacterium, but fungi and mammalian cells could also be used. Some applications are developed and used in containment while others – known as field applications – are deliberately released.

On the following pages we outline a selection of applications that have been developed by researchers and businesses. The descriptions are taken directly from the researchers, owners, or manufacturers. By including them we are not advocating the applications or vouching for the accuracy of the descriptions.

Because there is no one agreed definition of synthetic biology, opinions vary over whether these are true applications.

For more information on types of synthetic biology and potential applications – including some of the key challenges raised – see the Further reading section (page 72).

Synthetic artemisinin

Owner: Sanofi

Owner's description:

- Artemisinin is an antimalarial drug precursor.
- The price and supply of botanical artemisinin, derived from the sweet wormwood plant, are volatile which has resulted in periodic shortages in the past.
- Sanofi manufactures large batches of antimalarial treatments using a new semisynthetic artemisinin derivative.
- According to Sanofi, by complementing botanically-derived supplies, the new option can widen access to treatment for millions sickened by malaria every year.
- This application is in production and commercial use.

Source: Sanofi press release August 2014

Synthetic vanillin

Owner: Evolva

Owner's description:

- Natural vanillin is one component of the extract from the vanilla bean.
- According to Evolva, 'Vanilla and vanillin are together among the most important fragrance and flavouring products in the world, with the total market worth approximately US$600 million (and a total volume of approx. 18,000 tonnes). Only a small fraction of this volume consists of natural vanilla, with the vast majority being synthetic vanillin.'
- Evolva uses 'a yeast-based fermentation route' to produce the synthetic vanillin.
- This application is in production and commercial use.

Sources: Evolva website March 2015

Household cleaning products

Owner: Solazyme

Owner's description:

- Currently palm oil is used in most household cleaners.
- Manufacturer Solazyme claims algal oil is a potential substitute for palm kernel oil in household cleaners.
- Solazyme states that algal oil is produced through traditional genetic engineering and industrial fermentation of microalgae.
- Several types of feedstock are being investigated, including sugarcane and agricultural and forest waste, to identify which is the most sustainable of the locally available options.
- This application is in production and commercial use.

Source: Solazyme website March 2015

‘Cow-free’ milk

Owner: Muufri

Owner’s description:

- The world population is soaring and less land is available for agriculture. According to Muufri, cow-free milk addresses these resource constraint and removes the need for unethical dairy factory farms.
- Muufri’s ‘synthetic’ milk is derived from yeast. The technology replicates the cellular machinery involved in biological synthesis of each individual component of milk in yeast.
- This ‘synthetic’ milk is lactose and cholesterol free and does not require pasteurisation.
- This application is in R&D and not yet in commercial use.

Source: Moo-ve over, Factory Farms: Muufri is Taking Dairy Milk Animal-free
Muufri website March 2015
http://muufri.com/

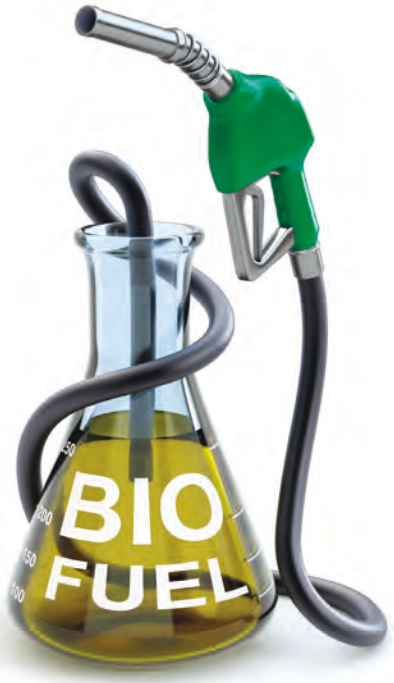
Biofuels from blue-green algae (cyanobacteria)

Owner: Algenol

Owner's description:

- Algenol's Direct to Ethanol® technology uses sunlight, algae, non-arable land and CO_2 to produce ethanol and spent algae that can be converted into other biofuels. This proprietary technology uses enhanced blue-green algae (or cyanobacteria) and photosynthesis to convert CO_2 and seawater into 'sugar' (pyruvate) and then into ethanol and biomass.
- Algenol enhances a natural ability found in many strains of cyanobacteria to produce ethanol by over-expressing fermentation pathway enzymes, channelling the majority of photosynthetically fixed carbon into ethanol production rather than routine cell maintenance.

Source: Algenol website March 2015



Bioluminescent plants

Owner: Glowing Plant

Owner's description:

- In 2013, a Kickstarter campaign funded Glowing Plant – a light-producing plant. Glowing Plant 'are using synthetic biology techniques and genome compiler's software to insert bioluminescence genes into Arabidopsis, a small flowering plant and member of the mustard family, to make a plant that visibly glows in the dark (it is inedible)'.
- The developers also say that they publicised this application in an effort to raise the profile of synthetic biology. They also want to encourage lighting applications that don't require electricity. This application is in development.

Sources: Glowing Plant Kickstarter website March 2015
Glowing Plant website March 2015
http://www.glowingplant.com/

Self-limiting mosquitoes

Owner: Oxitec

Owner's description:

- Self-limiting is the name given to Oxitec's solution for the control of dangerous and damaging insects. This self-limiting approach uses modern biotechnology and advanced genetics to provide effective, safe and sustainable control of insect pests.
- Oxitec insects contain a genetic modification that causes their offspring to die, but the Oxitec insects can live and reproduce normally when they are fed a diet containing an antidote.
- Oxitec males are released to mate with wild female pest insects; their offspring inherit the self-limiting gene and do not survive to adulthood. Releases of Oxitec males in large enough numbers over a sufficient time will suppress, or even eliminate, the target pest population.
- This application is being trialled.

Sources: Oxitec website March 2015

Synthetic rubber for tyres

Owner: Goodyear and Dupont

Owner's description:

- Due to huge global demand for rubber, synthetic rubber has been used in tyres for many years. Until 2012 it was invariably produced using petrochemical sources.
- DuPont, together with Goodyear, announced in March 2013 that they were 'working together to develop BioIsoprene™, a bio-based alternative for petroleum-derived isoprene. BioIsoprene™ can be used for the production of synthetic rubber–which in turn is an alternative for natural rubber– and other elastomers. The development of BioIsoprene™ will help reduce the tyre and rubber industry's dependence on oil-derived products.
- Dupont and Goodyear describe this as a 'reliable, high-efficiency fermentation-based process' for BioIsoprene™.
- This application is in development.

Sources: Goodyear Press Release 6 March 2012
Biotechnology Industry Organisation website March 2015
https://www.bio.org/articles/current-uses-synthetic-biology

Deliberative questions

Using the deliberative questions

In this section you will find 14 questions designed to help you systematically deliberate the key sustainability considerations for any synthetic biology application. You'll notice that they correspond to the factors highlighted in the infographic (page 12).

By carefully considering the questions and exploring different perspectives as you do so, you will gain a more holistic view of the application you are considering. You will be better equipped to engage in dialogue about the application and to make better informed, more sustainable decisions. The process may also help you to communicate more clearly about any decision you make.

You can work through the questions alone, or as part of a group, although the more discussion and debate the better. Remember to allow enough time to really think about each question. This is a complex area, and deserves very careful consideration.

We suggest you consider each question and the prompts supplied in turn, noting down your response and considering how different stakeholders might perceive it. You may of course opt to gather input directly from stakeholders themselves – this will require resources, but will make for a very robust decision-making process.

Either way, try to consider as broad a range of stakeholders as possible, taking into account different professions, backgrounds, levels of awareness of synthetic biology and value systems. We have provided some suggested approaches to help you with this in the Further resources section (page 56). For each question, take time to consider the different issues and opportunities that stakeholders may raise. Do they highlight any benefits you had not considered before, or highlight areas for improvement? Are there any issues that cannot be addressed, and what does this mean for the application and your next steps? Remember, the complexities of the topic mean there are no right or wrong answers, and there will never be consensus.

Before you start, you will need to gather together information on the specific application that you are considering. This can be challenging to find and to verify. It is important to bear in mind where this information has come from and how certain you are of its content when working through the questions.

Questions to consider

#	Factor	Question	Prompts
1	Purpose	Does this application contribute to solving the major challenges of our time, or does it exacerbate them?	Does it significantly help address poverty, inequality, hunger, malnutrition, wellbeing, access to safe water and sanitation, climate change, ecosystem health, or resilience for example? What need does this application meet? Could it be used for an even greater purpose over time? Does it create a need or dependence in any way?
2	Alternatives	Are there other ways to meet this need?	What alternative ways are there to meet this need, either currently or in development? Does the application take a meaningful step beyond what is already available? Does it solve a challenge associated with any alternative solutions? How does it impact the alternatives and the power balance in the value network? Does it preclude or limit the potential for alternatives to exist? Does it close down or limit alternatives that may be more sustainable?
3	Equality	Are the benefits of this application fairly distributed?	Does it address or exacerbate inequality? Will it make the world a fairer place? What is the scale of this benefit? What is the significance of this benefit?
4	Unintended consequences	How can potential misuse or other unintended consequences be managed?	Could the application be harnessed for terror or other negative purposes? Is the potential high for this to happen? Would the impact of misuse be significant? How can these risks been managed? What processes are in place to monitor, foresee and act on unintended consequences? How are they being managed?
5	Resource use	How does the application impact resource supply and security?	What resources are used throughout the value chain? Are they under stress now or in the future? Is the application reliant on a specific resource or can feedstocks be readily changed? Does it maximise the value of all feedstocks? Does the process make the most efficient use of resources? How does using the inputs and feedstocks affect the availability of resources such as food and energy? Does the product enable efficient use of resources?
6	Health	How is human health being safeguarded?	Does this application have health benefits? What are the health risks for this application in the short, medium and long term? What health and safety measures are in place? Do they cover workers, communities, consumers and wider society? Do they cover the entire life cycle of the application? Are they independently monitored?

7	Livelihoods	How does the application impact upon people's livelihoods?	Does the application enable sustainable livelihoods? Does it reduce, destabilise or put at risk the income of people in the original or alternative value chain? Could it cause significant, long term unemployment? Does it impact on worker rights or land rights? Does it empower or disempower people or communities? How might you mitigate any negative impacts on communities?
8	Biodiversity	How does this application impact biodiversity and ecosystems?	What environmental health risks are present in the sourcing and processing of inputs? How are they being managed? What practices are employed in the supply chain to optimise and benefit biodiversity? Does the product itself benefit biodiversity or challenge it in any way? What biodiversity impacts occur when the product is disposed of?
9	Containment	How is the synthetic material/organism developed, grown and used?	Will it be contained in development and use? What would the consequence be of release beyond what is intended? What safety measures are in place? How is it controlled? Who oversees this control?
10	Reversibility	How readily can the application be withdrawn or the effects reversed?	How is the application withdrawn or the effects reversed? What would it cost to recall the application? Who would bear this cost? What remediation would be required? What plans are in place to ensure this can be done quickly with minimal impact?
11	Level of change	To what extent will the product perform a different role to its original counterpart?	Is this causing an organism to act in a different way to its original state? What are the impacts of the organism performing new or different functions within the ecosystem? Is this developing a new species? What impact will this new species have above and beyond the original? How are these considerations being managed? Is this demonstrating scientific excellence?
12	Transparency	How is the use and management of synthetic biology being communicated?	Can people engage with application owners meaningfully? How does this engagement build trust? Is it clear that the product has been developed using synthetic biology? Is the process available and accessible to the general public? Is it clear how the risks and benefits are being managed throughout the value chain? Can people make their own informed decision based on the information provided?
13	Governance	What governance controls are in place?	How is this application regulated? Is this regulation enforced? What voluntary agreements or standards does it apply? Do these regulations and agreements cover the major risks now and in the future? What formal and informal governance structures and mechanisms manage and oversee the development of this application? Are countries and regions able to choose whether the application is deployed in their area? Who is responsible for the impact – foreseen or otherwise – and how are they held accountable?
14	Ownership	What ownership model is being used?	Who owns the IP? Who is accountable for how this IP is used? How does this impact power dynamics? How are the contributors to this knowledge being recognised and compensated? Who will have access to the learning and knowledge developed? Will the blueprint for the process be available to others? Will the blueprint of the product be available to others? What charges and conditions will apply?

Purpose

Does this application contribute to solving the major challenges of our time, or exacerbate them?

- Does it significantly help to address any of the issues listed below, or any other challenges?
  - Poverty
  - Inequality
  - Hunger
  - Malnutrition
  - Wellbeing
  - Access to safe water and sanitation
  - Climate change
  - Ecosystem health
  - Resilience
- What need does this application meet?
- Could it be used for an even greater purpose over time?
- Does it create a need or dependence in any way?

Useful prompts

Purpose

How might different stakeholders with different perspectives (such as those in the personas on page 56) view your response?

What could be done to address any concerns raised by stakeholders?

Are there any issues that cannot be addressed?

Alternatives

Are there other ways to meet this need?

- What alternative ways are there to meet this need, either currently or in development?
- Does the application take a meaningful step beyond what is already available?
- Does it solve a challenge associated with any alternative solutions?
- How does it impact the alternatives and the power balance in the value network?
- Does it preclude or limit the potential for alternatives to exist?
- Does it close down or limit alternatives that may be more sustainable?

Useful prompts

Alternatives

How might different stakeholders with different perspectives (such as those in the personas on page 56) view your response?

What could be done to address any concerns raised by stakeholders?

Are there any issues that cannot be addressed?

Equality

Are the benefits of this application fairly distributed?

- Does it address or exacerbate inequality?
- Will it make the world a fairer place?
- What is the scale of this benefit?
- What is the significance of this benefit?

Useful prompts

Equality

How might different stakeholders with different perspectives (such as those in the personas on page 56) view your response?

What could be done to address any concerns raised by stakeholders?

Are there any issues that cannot be addressed?

Unintended consequences

How can potential misuse or other unintended consequences be managed?

- Could the application be harnessed for terror or other negative purposes?
- Is the potential high for this to happen?
- Would the impact of misuse be significant?
- How can these risks been managed?
- What processes are in place to monitor, foresee and act on unintended consequences?
- How are they being managed?

Useful prompts

Unintended consequences

How might different stakeholders with different perspectives (such as those in the personas on page 56) view your response?

What could be done to address any concerns raised by stakeholders?

Are there any issues that cannot be addressed?

Resource use

How does this application impact resource supply and security?

- What resources are used throughout the value chain?
- Are they under stress now or in the future?
- Is the application reliant on a specific resource or can feedstocks be readily changed?
- Does it maximise the value of all feedstocks?
- Does the process make the most efficient use of resources?
- How does using the inputs and feedstocks affect the availability of resources such as food and energy?
- Does the product enable efficient use of resources?

Useful prompts

Resource use

How might different stakeholders with different perspectives view your response?

What could be done to address any concerns raised by stakeholders?

Are there any issues that cannot be addressed?

Health

How is human health being safeguarded?

- Does this application have health benefits?
- What are the health risks for this application in the short, medium and long term?
- What health and safety measures are in place?
- Do they cover workers, communities, consumers and wider society?
- Do they cover the entire life cycle of the application?
- Are they independently monitored?

Useful prompts

Health

How might different stakeholders with different perspectives view your response?

What could be done to address any concerns raised by stakeholders?

Are there any issues that cannot be addressed?

Livelihoods

How does the application impact upon people's livelihoods?

- Does the application enable sustainable livelihoods?
- Does it reduce, destabilise or put at risk the income of people in the original or alternative value chain?
- Could it cause significant, long term unemployment?
- Does it impact on worker rights or land rights?
- Does it empower or disempower people or communities?
- How might you mitigate any negative impacts on communities?

Useful prompts

Livelihoods

How might different stakeholders with different perspectives (such as those in the personas on page 56) view your response?

What could be done to address any concerns raised by stakeholders?

Are there any issues that cannot be addressed?

Biodiversity

How does this application impact biodiversity and ecosystems?

- What environmental health risks are present in the sourcing and processing of inputs?
- How are they being managed?
- What practices are employed in the supply chain to optimise and benefit biodiversity?
- Does the product itself benefit biodiversity or challenge it in any way?
- What biodiversity impacts occur when the product is disposed of?

Useful prompts

Biodiversity

How might different stakeholders with different perspectives (such as those in the personas on page 56) view your response?

What could be done to address any concerns raised by stakeholders?

Are there any issues that cannot be addressed?

Containment

How is the synthetic material/organism developed, grown and used?

- Will it be contained in development and use?
- Will it be contained in development and use?
- What would the consequence be of release beyond what is intended?
- What safety measures are in place?
- How is it controlled?
- Who oversees this control?

Useful prompts

Containment

How might different stakeholders with different perspectives (such as those in the personas on page 56) view your response?

What could be done to address any concerns raised by stakeholders?

Are there any issues that cannot be addressed?

Reversibility

How readily can the application be withdrawn or the effects reversed?

- How is the application withdrawn or the effects reversed?
- What would it cost to recall the application?
- Who would bear this cost?
- What remediation would be required?
- What plans are in place to ensure this can be done quickly with minimal impact?

Useful prompts

Reversibility

How might different stakeholders with different perspectives (such as those in the personas on page 56) view your response?

What could be done to address any concerns raised by stakeholders?

Are there any issues that cannot be addressed?

Level of change

To what extent will the product perform a different role to its original counterpart?

- Is this causing an organism to act in a different way to its original state?
- What are the impacts of the organism performing new or different functions within the ecosystem?
- Is this developing a new species?
- What impact will this new species have above and beyond the original?
- How are these considerations being managed?
- Is this demonstrating scientific excellence?

Useful prompts

Level of change

How might different stakeholders with different perspectives (such as those in the personas on page 56) view your response?

What could be done to address any concerns raised by stakeholders?

Are there any issues that cannot be addressed?

Transparency

How is the use of synthetic biology being communicated?

- Can people engage with application owners meaningfully?
- How does this engagement build trust?
- Is it clear that the product has been developed using synthetic biology?
- Is the process available and accessible to the general public?
- Is it clear how the risks and benefits are being managed throughout the value chain?
- Can people make their own informed decision based on the information provided?

Useful prompts

Transparency

How might different stakeholders with different perspectives (such as those in the personas on page 56) view your response?

What could be done to address any concerns raised by stakeholders?

Are there any issues that cannot be addressed?

Governance

What governance controls are in place?

- How is this application regulated?
- Is this regulation enforced?
- What voluntary agreements or standards does it apply?
- Do these regulations and agreements cover the major risks now and in the future?
- What formal and informal governance structures and mechanisms manage and oversee the development of this application?
- Are countries and regions able to choose whether the application is deployed in their area?
- Who is responsible for the impact – foreseen or otherwise – and how are they held accountable?

Useful prompts

Governance

How might different stakeholders with different perspectives (such as those in the personas on page 56) view your response?

What could be done to address any concerns raised by stakeholders?

Are there any issues that cannot be addressed?

Ownership

What ownership model is being used?

- Who owns the IP?
- Who is accountable for how this IP is used?
- How does this impact power dynamics?
- How are the contributors to this knowledge being recognised and compensated?
- Who will have access to the learning and knowledge developed?
- Will the blueprint for the process be available to others?
- Will the blueprint of the product be available to others?
- What charges and conditions will apply?

Useful prompts

Ownership

How might different stakeholders with different perspectives (such as those in the personas on page 56) view your response?

What could be done to address any concerns raised by stakeholders?

Are there any issues that cannot be addressed?

Deliberation summary

What aspects of this application highlighted benefits for different stakeholders?

What aspects raised concerns for different stakeholders? Can their concerns be adequately addressed?

What will you do as a result of considering these questions and perspectives?

Next steps

What additional information do you need?

Who would you like to speak to?

What will you do next to help act on these insights?

In the longer term, what will you do differently as result of considering these questions and perspectives?

Further resources

A range of perspectives

We believe that it is essential to consider different perspectives on synthetic biology, in order to highlight a broad range of risks, opportunities and areas for improvement. It also encourages openness and empathy, both of which are essential to sustainable decision making.

There are a number of ways to find out more about the different perspectives held on synthetic biology, including:

- **Face-to-face:** Engaging in direct dialogue with stakeholders is an excellent way to gain an insight into their views.
- **Previous dialogue summaries:** The dialogue on synthetic biology commissioned by the BBSRC in 2010 gives a good summary of UK perspectives on synthetic biology, and challenges some commonly held assumptions **http://www.bbsrc.ac.uk/engagement/dialogue/activities/synthetic-biology/**
- **Articles and campaigns:** There are many very informative opinion pieces available on the risks and benefits of synthetic biology from various perspectives including NGOs, scientists and policy makers. See page 74 for a list of useful materials with links and references.
- **Personas:** Using fictional pen portraits of people can help bring perspectives to life. This technique is used widely in marketing and research. You will find a collection of personas on the following pages.

Personas

These personas are designed to be used alongside the methods set out on the previous page. For each question that you consider, try to imagine what each of the following people would think of your response.

The personas all have different views about the environment and society and issues relating to synthetic biology, along with varying levels of awareness and understanding of the technology. All their perspectives are equally valid. They are not based on real people, and in reality most people will represent a blend of more than one of the personas.

Challenges
These personas are not perfect. While they do highlight many of the concerns and opportunities voiced currently, and were developed using existing materials such as the BBSRC dialogue findings from 2010, they are not based on enough research to comprehensively and representatively set out the full range of views.

We would like them to be developed further so that they become more representative and would welcome support in boosting the rigour of these personas, using high quality social science.

Currently, they purposefully do not include anyone apathetic to synthetic biology, although this may in fact be the majority view. This is important to bear in mind, and an area that we would like to see developed. Also, all the personas are UK-based, albeit set in a global context. It would be helpful to have personas that help people understand international viewpoints as well.

The personas
The next page provides a brief introduction to each person. This is then followed by a more in-depth description of the personas that aims to help you step into their shoes.

Meet the personas resource

Zahra

A mother of two with another child on the way. Works as at the local café as a waitress. Money is a real worry. Each month it is a struggle to cover the bills. Not familiar with ‘synthetic biology’. Nervous of biotechnologies because, deep down, she mistrusts the science. She likes to know exactly what is in the products that she buys, and tries to avoid foods containing GMO. She may consider synthetic biology acceptable if it could help solve her son’s health problems and doesn’t mean additional costs.

Javier

Recently married in an understated ceremony to Bella. Award-winning freelance writer and photographer, specialising in indigenous communities in Latin America, and co-founder of a successful digital image agency. He has some understanding of synthetic biology and thinks it introduces unnecessary and unknown risks which, on past experience, will not be well regulated because economic interests will triumph. For Javier, inequality is where our efforts should be focused.

George

A grandfather of six, George lives alone having been widowed two years ago. He draws great comfort from his fellow worshippers and is active in running his parish. He has some understanding of synthetic biology, having lectured in biology for 40 years. He feels we need to recognise the limits of our own knowledge, even though he is passionate about constantly striving to improve this. He is conscious of stepping over the line of what we have the wisdom to do as a species.

Audrey

Gained recognition in the field of biotechnology for her ground breaking PhD looking at its application to chemical clean-up operations. Prefers to be hands on and believes some bureaucracy unnecessarily slows down new development. In her view our knowledge of genetics is rocketing, and the capabilities to develop and deploy synthetic biology safely (with minimal and broadly quantifiable risks) exist. She is very in favour of self-government and openness, care and transparency .

Ravish

Despite being one of the youngest and most respected board members in retail, Ravish still comes second to his doctor older brother in his mother’s eyes. He is desperate to start a family but his wife refuses so long as he spends 80% of his life away from home. He knows a little about synthetic biology and feels we should embrace technological advancement generally. The 8 billion people in this world have the right to a standard of living that is taken for granted in the West, and he feels synthetic biology could help make that possible more quickly.

Jo

Recently promoted into a strategic role at a government office on a fast-track graduate programme. Jo has just bought her first home and is now paying off her first mortgage with boyfriend Simon. She has a low understanding of synthetic biology and is fascinated with systems and their inherent unpredictability. She would embrace synthetic biology if the public health risk was low and all the performance risks could be managed, but would be nervous of unintended consequences.

Zahra
A mother and waitress

Quick take

- Mother of two with another child on the way.
- Lives with her husband, Mikkel, but he's often away with work.
- Works at a local café as a waitress. Earning enough to cover the bills is a constant concern.
- Not familiar with 'synthetic biology'.

'There isn't enough time in the day to get everything done, but that is no excuse for not considering your actions.'

A moment in their shoes

Mikkel has returned from the supermarket with a different brand of washing powder to the usual. It's a bargain that Zahra is suspicious of, and she is reading the label. She is incredibly price conscious but she is nervous of aggravating Alexis' eczema, and that the kids don't develop any other skin conditions. Being pregnant has meant that she is watching this far more than she normally would. She's the first to admit she is no expert but she's read around since Alexis developed his eczema and found it so hard to know what to believe about the ingredients to avoid or go for that she has decided to stick to basic products that have been used in her family for generations.

Zahra
A mother and waitress

View of environment:
Nature is fragile and usually 'knows best'. The chemicals we put in and around our bodies are damaging ourselves and nature, risking cancers, diseases and other silent health problems.

Outlook:
Both optimistic and pessimistic. Concerned that so many children have asthma and are overweight these days. Optimistic because the government is introducing new policies and initiatives – like the smoking ban – to improve health.

Social context:
She would like to be sure that what she buys is produced without exploitation. She'll occasionally buy fair-trade, but cost is a huge issue with a family to support and often wins out.

Motivation:
A happy, healthy family drives many of Zahra's decisions. She wants to be informed and able to make the 'right' decisions for herself and them. She has a strong sense of fairness towards others.

Risk profile:
Zahra is nervous of biotechnologies because, deep down, she mistrusts the science. She sticks to what she knows when buying products that come into contact with the body, to avoid the risk of allergic reactions. She's been buying the same brands of food, beauty, laundry detergent and washing-up liquid for years. She recalls the BSE crisis and has heard headlines relating to regenerative medicine and cloning. While Zahra doesn't know the detail of how it's done, she is uncomfortable with the idea of genetically modifying foods.

She thinks cross contamination of 'natural' species and other unintended consequences might happen even with regulation in place. She tries to avoid foods containing GMO though is aware she probably isn't managing to fully. If synthetic biology could produce medicines or solve illnesses in people and animals – like Alexis's eczema – she might embrace it. Today, Zahra isn't aware of the technology and would probably be alarmed at its description.

Javier
Co-founder of successful digital image agency

Quick take

- Recently married in an understated ceremony to Bella
- Award-winning writer and photographer, specialising in Latin America
- Co-founded a digital image agency seven years ago which is now very successful
- Some understanding of synthetic biology.

'Everything you do has an impact on others and the world around you. Be conscious and respectful in your actions.'

A moment in their shoes

Javier is sat looking at the wedding gifts that have amassed in the corner of his small lounge. He and Bella expressly said that they didn't want anyone to give gifts. They knew that was unusual, particularly to their parents' generation, and asked for donations to a small favela-based sanitation charity if people really wanted to give a token. But they have given presents all the same. And he feels guilty for feeling ungrateful. People have been so generous. One gift that is particularly troubling him is a gift voucher for a weekend away in a beautiful hotel. Unfortunately the company that runs the hotel has been highlighted as being complicit in a recent planning scandal that resulted in an area of favela being razed to the ground, leaving over 300 families homeless. Javier knows some of these families. One of them made the best feijoada in town. Javier and Bella won't go, and somehow Javier wants to explain this to the generous givers without offending them, helping them to understand why he feels that they too must avoid this company in the future.

Javier
Co-founder of successful digital image agency

View of environment:
Nature is complex and precarious. The more vulnerable and unstable natural systems become, the greater the risk to our wellbeing. We need to find harmony with nature if we are to flourish.

Outlook:
Pessimistic. Humans should be in partnership with nature, but we operate as if we have and want dominion – when we don't and shouldn't. It's the poorest in our society that will feel the worst consequences. We need a radical overhaul of global governance on climate change, and comprehensive action. He sees a collective failure to learn lessons from CFCs, PCBs, biofuels, etc.

Social context:
Most decisions are made by a powerful minority to serve their own interests. Javier's experience with indigenous cultures has continuously reinforced this view. He thinks new technologies fail to recognise nature's intricacies and either ignore, or put at risk, the needs of the bulk of the world's population.

Motivation:
He feels a responsibility to speak out for and with the poorest in the world – the people he meets every day – and to speak out for nature. It would be possible to avoid another 'PCB/CFC/etc. mess' if only we were more proactively conscious of the consequences of our actions. Through his work, he tries to show the need for systemic action, not just narrow responses to single issues.

Risk profile:
Javier thinks that there are better ways of meeting societal needs than with synthetic biology – like tackling inequality. He believes synthetic biology will distract from these and, at best, deal with symptoms not causes of problems whilst introducing unnecessary and unknown risks which, on past experience, will not be well regulated because economic interests will triumph.

Javier opposes the use of synthetic biology, except in exceptional circumstances. These might include medicine, where alternative approaches don't exist and circumstances are grave; or for public and community 'good' – not profit. If so, it must be in tightly controlled and regulated environments, and absolutely not in the field.

George
A retired professor

Quick take

- A grandfather of six, George lives alone having been widowed two years ago
- He draws great comfort from his fellow worshippers and is active in the running of his parish
- Some understanding of synthetic biology. He likes to keep up to speed on science.

'Everything happens for a reason. Even if it takes a while to listen to the lesson, it will be there waiting.'

A moment in their shoes

George has just returned from locking up the playing field for the night – not that it will keep out anyone who really wants to get in. He much prefers the more preventative tack that some of the local residents are pushing for. He's read a lot about how creating a sense of shared ownership and responsibility for public property can prevent damage far more than the traditional 'keep out' approach. Besides, these kids aren't bad. No one is in the eyes of God. They just haven't been brought up to respect what's not theirs, and that attitude can change with the right support. It's our responsibility to help show them the way, and guide them into a better life. It is difficult though. Seeing so many students from all sorts of backgrounds go through his lectures has given him a sense of empathy with younger adults that he feels is quite unusual. He thinks about his past students, and his grandchildren for that matter. How life seemed simpler when he was growing up. But then the war meant you appreciated how important other people are to you, even strangers.

George
A retired professor

View of environment:
We should revere and look after nature. Even with all the scientific advancement we are seeing, we will never know all there is to know. We are taking it for granted; being wasteful. We are treating ecology like a shared bank account with an unlimited overdraft. It's up to us to recover and maintain the balance.

Outlook:
Pessimistic. Too many people have lost their way, prioritising money and self-interest over sharing and community. People are poor because of the greed and materialism of others; there isn't a technological route out of that. George thinks the only way forward is to change our mind-set: to be content.

Social context:
We're all accountable and responsible for our actions and have a duty to contribute to society. Mutual respect is vital, for each other and for the creation around us. George thinks ignoring our responsibilities today is storing up problems and deprivation for people in the future, which is just wrong.

Motivation:
To do what is right, as guided by his faith and by his appreciation of science. George stays on top of the latest scientific research despite retiring 15 years ago. He writes the local pub quiz most weeks, thoroughly enjoying the research.

Risk profile:
George acknowledges that our understanding of our place in nature has increased through scientific research, but believes that we need to recognise boundaries and should not be arrogant about our level of knowledge and what is within our gift. He believes designing and creating life from scratch will always be beyond our grasp.

This is stepping over the line of what we have the wisdom and authority to do as a species in his view. He has confidence in the scientists in this area however, to be seeking new knowledge and understanding for good reason. Like any area of new science he believes that we are a long way from understanding the long term consequences enough to be sure that it will not fundamentally unbalance nature's systems. George respects the choices of others to work in this area but would avoid it himself.

Audrey
An academic turned entrepreneur

Quick take

- Gained recognition in the field of biotechnology for her ground-breaking PhD looking at its application to chemical clean-up operations
- Prefers to be hands on, and believes some bureaucracy unnecessarily slows down new development
- Understands synthetic biology very well.

'Theory is great, but it's not real till you can hold it in your hand.'

A moment in their shoes

Audrey is stood at the front of the crowd listening to the politician make his speech. It's funny to see someone in a suit in her lab. Everyone else is in jeans and jumpers, with the occasional lab coat. She's proud to host the gathering. Audrey completely agrees that biotech is a real area of potential and can play a massive part in economic growth for the country (her own company is booming after all), so she's happy to deal with a day of pomp.

She is intrigued to hear what he has to say about governance and regulation. She looks across to the keen community of 'biohackers' that regularly show up to the lab with their sparky intelligence and new ideas, hungry to make a difference in the world, and she feels a surge of hope for what we can achieve as a species. Her fiancé isn't so sure. Their conversations always come round to whether she can tell if one of her community would ever use it for ill. Six years together and they still debate this fiercely!

Audrey
An academic turned entrepreneur

View of environment:
Nature is inspiring and resilient. It does have its limits – so if you push too far you're likely to get significant adverse consequences. We're consuming so much, nature can't recover or adapt quickly enough. Technology has an important part to play in curbing the pressure and rate of decline.

Outlook:
Both pessimistic and optimistic. Pessimistic because our populous world is under pressure, and inequality, unrest and crises are increasing; optimistic because institutions and their tendency to serve themselves first are part of the problem and the digital revolution is opening up new possibilities to challenge and offer alternatives by facilitating a return to participative democracy.

Social context:
Audrey wants synthetic biology technologies to be used responsibly and made widely available. It could be the ultimate empowering technology if the people best placed to understand the problems they face are the ones to develop the solutions. For her, this means stopping big business and politicians from patenting it and controlling it.

Motivation:
Audrey believes in the power of human creativity, ingenuity and cooperation and is suspicious of the 'establishment'. She is thrilled at how quickly the science is evolving and, within that, at what she could personally accomplish.

Risk profile:
Synthetic biology is difficult to regulate and manage in a traditional way. Audrey says there are already students experimenting on their own terms. She says our knowledge of genetics is rocketing, and the capabilities to develop and deploy synthetic biology safely (with minimal and broadly quantifiable risks) exist. The risks of unintended consequences increase if enthusiasts go 'off-grid' so it needs self-government and openness, care and transparency.

She does have concerns that some 'nutters' might use synthetic biology for biological weapons (including governments) or muck about with dangerous diseases. But she will only accept regulation to control very dangerous uses.

Ravish
An executive with a multinational retailer

Quick take

- Despite being one of the youngest and most respected board members in retail, Ravish still comes second to his doctor older brother as the apple of his mother's eye
- He is desperate to start a family but his wife refuses so long as he spends 80% of his life away from home
- Knows a little about synthetic biology.

'Work hard and you will reap the rewards.'

A moment in their shoes

Ravish finds aeroplanes difficult to sleep on at the best of times. But it is his mind rather than his physical discomfort that is bothering him now. He should be happy, he tells himself. He has just closed the deal that will bring his company into one of the biggest markets in the world. But several things are nagging at him.

From a business perspective, there was something too vague in the responses he got on ensuring good governance and anti-corruption measures. The policy was there, but when he asked them to run through the practice once again, the alarm bells rang. He had had his fingers burnt with this before.

The days when your business could claim to be an upstanding citizen in one market and expect to be able to turn a blind eye in another are long gone thanks to social media. More personally, his concerns mean spending more time thrashing the issues out, which means more time away from home, and the dream of having a family.

Ravish
An executive with a multinational retailer

View of environment:
Most landscapes and ecosystems have been or are being shaped by human activity in some way. By default, the distinction between 'natural' environments and 'industrial' environments is becoming arbitrary. With that in mind, we need to rethink the environmental challenges we are facing.

Outlook:
Optimistic. Environmental and social issues are a boardroom issue in multinational retailers as never before and the economy is growing. There's huge potential for business to win by being part of the solutions. We want to be around for the long-term, while politicians chase short-term political interests.

Social context:
We're global consumers and citizens, and that's how business and retail increasingly sees itself too. We have to be alive to our social impacts and actively deal with supply chain issues. We can provide jobs through our operations and can ensure goods are accessible and more affordable for many more people, through efficiency and scale.

Motivation:
Our job is to make money for our shareholders, but we want to do this in a way that is good for our employees and partners in the supply chain. We want to minimise our environmental footprint and be responsible, but you can't run a multinational operation with zero impact.

Risk profile:
Ravish believes we can and should embrace technological advancement. Of course there should be regulation, but he believes that far too often regulators kill commercial opportunity by being overly cautious and prescriptive. The 8 billion people in this world have the right to a standard of living that is taken for granted in the West, and synthetic biology could help make that possible more quickly.

Ravish believes it could be used to help solve some of the big challenges within supply chains, including synthetic biology in the field, though they'd move into that with more caution because of the risk of consumer backlash. It could open up 'new product' innovations. He's very keen to be transparent and open about ingredients and products, and isn't against against labelling, but it shouldn't confuse or cause unnecessary alarm.

Jo
A transport planner

Quick take

- Recently promoted into a strategic role at a government office on a fast-track graduate programme
- Jo has just bought her first home and is now paying off her first mortgage with boyfriend Simon
- Low understanding of synthetic biology.

'Remember to expect the unexpected….'

A moment in their shoes

Jo has been poring over the map of what happened in the paper for an hour. Somehow the scale and surprise of the attack has numbed her. The details of what happened, where the gunmen went and how they travelled are all laid out before her. Jo knows this city. She studied there on exchange, and still has friends that live there.

Her social media shows how shocked they all are. She can't see the logic in their movements. But maybe what she is seeing is panic, she thinks, or perhaps the movements of people resigned to their destiny.

Jo has read a fascinating article about how intelligence agencies are using algorithms to find serial killers by predicting their behaviour and movements, and pinpointing where they are likely to live. She wonders whether this could ever be applied to terrorists. Perhaps it could help to locate where they get their weapons from, she thinks. But a sense of futility clouds out that thought as her mind moves to all the different possible means of terrorism and how more are being found, and used, by the day.

Jo
A transport planner

View of environment:
Extreme weather events point out the flaws in our system models and show us that we can never predict what will happen in every eventuality. On the flip side, extreme weather events can help with air quality by clearing the air!

Outlook:
Neither optimistic or pessimistic. Mobility is vital for the economy and society. It offers access to trade and relationships and, without it, we can be excluded and disadvantaged. We can't possibly accurately predict what will be needed, when and by whom. We set systems up then use market forces and data to help decide improvements.

Social context:
By affecting how people behave, the systems we design have a host of social impacts – like racial tension, access to work and community cohesion. They shape a person's life in ways that aren't obvious. Jo thinks more needs to be done to get traffic and road accidents down, and to tackle digital exclusion among older generations.

Motivation:
Jo is obsessed with systems modelling. She gets a kick out of playing through different scenarios to identify ways of improving efficiency. The possibility of terrorist attacks is the scenario that tests her mathematical abilities most. She has to keep reconsidering it in light of new intelligence.

Risk profile:
Any technology would need to be fully tested and approved against a recognised safety standard. The risks would have to be owned by a licensing body of some kind, for it to be acceptable on the transport system. Jo can think of wild possibilities for how her architects and engineers could put synthetic biology to use on the system: it could offer sophisticated air quality and noise sensing; self repairing pavements and sewerage pipes could save a fortune each year, for example, but could also cost jobs for contractors.

What would it do to her public health risk profile? She doesn't know enough about it, but knows this would be a factor in any decision to use it – as would public perception at large. If it can save precious funds and tick the boxes, Jo is supportive.

Synthetic biology application

Types of synthetic biology application

	Contained use	Deliberate release
Using the product	e.g. Artemisinin; diabetes treatments; oils for biofuels; Muufri milk Here an organism created with synthetic biology is producing a product, typically in a fermentation vat. The product is the item of interest.	e.g. Oil from oil seed rape for fish food (**http://www.rothamsted.ac.uk/camelina**) Here an organism created with synthetic biology is grown in the field, possibly in a secure site, but it is the product of the organism which is of interest.
Using the organism	e.g. Artificial meat Here an organism created with synthetic biology is grown in containment, and it is the organism itself which is the product.	e.g. Self-limiting mosquitoes; bioluminescent plants Here a synthetic biology organism is released deliberately and it is the organism itself which is of interest.

Synthetic biology can be applied to many different organisms, ranging from viruses through bacteria, archaea and multi-cellular organisms. It could also be used in cell cultures of higher organisms like plants and mammals, and potentially human cells. Some researchers are looking into creating entirely new life-forms using synthetic biology and others are exploring the possibilities of creating organisms which aren't based on DNA.

Useful materials

Topic	Links or references
Synthetic biology definitions	**ETC** **http://www.etcgroup.org/issues/synthetic-biology** **UK Royal Society** **https://royalsociety.org/~/media/Royal_Society_Content/policy/projects/synthetic-biology/CallForViews.pdf** **Friends of the Earth** **http://www.foe.org/news/archives/2014-05-the-synthetic-biology-industrys-pr-scheme** **syntheticbiology.org** **https://openwetware.org/wiki/Synthetic_Biology:FAQ** **European Commission** EC (2005) Synthetic Biology: Applying Engineering to Biology, Report of a NEST High-Level Expert Group. Brussels, Belgium: European Commission **What is synthetic biology primer from Synberc**
Application: Artemisinin	**How semi-synthetic artemisinin is produced** Paddon CJ, Keasling JD, Semi-synthetic artemisinin: a model for the use of synthetic biology in pharmaceutical development. Nat Rev Microbiol. 2014 May;12(5):355-67. **Risks of large-scale production of semi-synthetic artemisinin** Marris C, **http://www.scidev.net/global/biotechnology/opinion/synthetic-biology-s-malaria-promises-could-backfire.html**
Application: Vanillin	**Biosynthesis of vanillin in yeast** Hansen EH et al., De novo biosynthesis of vanillin in fission yeast (Schizosaccharomyces pombe) and baker's yeast (Saccharomyces cerevisiae). Appl Environ Microbiol. 2009 May;75(9):2765-74.
Application: Algal oil	**Solazyme technology** **ETC Group open letter to Ecover/Method on use of Solazyme product** **http://www.etcgroup.org/content/open-letter-ecover-method** **Ecover response to ETC Group** **http://www.theecologist.org/blogs_and_comments/Blogs/2450666/ecover_is_as_green_as_ever.html**

Topic	Links or references
Application: Cow-free milk	**Muufri inventor perspective** Pandya, Ryan, 'Milk without the moo', New Scientist 222.2975 (2014): 28-29. **Consumer perspective** Qiu, Linda, National Geographic, **http://news.nationalgeographic.com/news/2014/10/141022-lab-grown-milk-biotechnology-gmo-food-climate/**
Application: Biofuels	**Current status of biofuel from algae as a renewable source** Firoz Alam et al., Biofuel from algae – is it a viable alternative?, Procedia Engineering, Volume 49, 2012 **Potential of microalgae** Gimpel JA, Specht EA, Georgianna DR, Mayfield SP, Advances in microalgae engineering and synthetic biology applications for biofuel production. Curr Opin Chem Biol. 2013 Jun
Application: Glowing plants	**Glowing Plant website** **http://www.glowingplant.com/** **Critics' perspective over release of glowing plants** **http://www.nature.com/news/glowing-plants-spark-debate-1.13131**
Application: Rubber from microbes	**Overview of the technology** **http://www.technologyreview.com/news/418159/rubber-from-microbes/** **ETC Group case study:** Synthetic biology's impact on livelihood and sustainable use of biodiversity **http://www.etcgroup.org/files/CBD_Rubber_case_study_TA.pdf**
Application: Mosquito control	**Responses to application for trial in Florida Keys** GenewatchUK: **http://www.genewatch.org/uploads/f03c6d66a9b354535738483c1c3d49e4/WHOconsul_GWresponse_1.PDF** **GM Watch commentary:** *GM Mosquitoes Fly Through Regulatory Gaps* **http://www.gmwatch.org/latest-listing/1-news-items/13979-gm-mosquitos-flying-through-regulatory-gaps** **Friends of the Earth US commentary:** *Genetically modi ied mosquitoes' survival rate concealed* **http://www.foe.org/news/news-releases/2012-01-genetically-modified-mosquitoes-survival-rate#sthash.597Jeknn.dpuf**

Topic	Links or references
Conservation	**Applications for conservation of biodiversity** Redford KH et al., Synthetic biology and the conservation of biodiversity. Oryx 48.03 (2014): 330-336. Redford KH et al., Synthetic biology and conservation of nature: wicked problems and wicked solutions. 2013
Clinical potential	**Clinical potential of synthetic biology** Ruder WC, Lu T, Collins JJ, Synthetic biology moving into the clinic. Science. 2011 Sep 2;333(6047):1248-52
Perspectives on synthetic biology	**Major challenges to date** Kwok R, Five hard truths for synthetic biology. Nature. 463:288-90 (2010) Balmer AS and Martin P, 'Synthetic biology: social and ethical challenges' (2008). **Civil society perspectives** SynBioWatch, Regulate Synthetic Biology Now: 194 Countries. Bhattachary D, Pascall Calitz J and Hunter A, 'Synthetic biology dialogue', Biotechnology and Biological Sciences Research Council and Economic and Social Research Council (2010).
Science of synthetic biology	**Synthetic biology and metabolic engineering** Nielsen J, Keasling JD, Synergies between synthetic biology and metabolic engineering. Nat Biotechnol. 2011 **Insights into a bottom-up approach to synthetic biology** Nandagopal N, Elowitz MB, Synthetic biology: integrated gene circuits. Science. 2011 **Engineering tools of synthetic biology** Silver PA, Way JC, Arnold FH, Meyerowitz JT, Synthetic biology: Engineering explored. Nature. 2014 Hodgman CE, Jewett MC. Cell-free synthetic biology: thinking outside the cell. Metab Eng. 2012
Other useful websites	**SYNBICITE:** Innovation and Knowledge Centre (IKC) dedicated to promoting the adoption and use of synthetic biology by industry (**http://synbicite.com/**) **Friends of the Earth U.S., International Center for Technology Assessment, ETC Group:** The Principles for the Oversight of Synthetic Biology. **Community to help partner the UK's research-base expertise in synthetic biology with relevant industrial communities. Community Synthetic Biology Special Interest Group (SynBio-SIG):** **https://connect.innovateuk.org/web/synthetic-biology-special-interest-group/overview** **Independent panel of experts reflecting a representative view for realising the potential of synthetic biology in the UK:** **http://www.rcuk.ac.uk/documents/publications/SyntheticBiologyRoadmap-pdf/**

Thank you for using this deliberation aid

- If you have feedback or comments, or would like to take this resource forward in any way please do get in touch
- Forum for the Future: **Anna Warrington a.warrington@forumforthefuture.org**
- BBSRC: **Patrick Middleton patrick.middleton@bbsrc.ac.uk**
- Friends of the Earth EWNI: **Mike Childs mike.childs@foe.co.uk**

Summer 2015

Version 2