ENGINEERING BIOLOGY EXPLAINED

# A guide to engineering biology and UK excellence in the field

UK BioIndustry Association

October 2018

# Foreword

The 21st century is proving to be one of the most exciting and prolific periods of innovation in biosciences and healthcare. Advances across biology, technology, engineering and data science are converging to help create new, potentially life-changing solutions for individuals and societies across the globe.

**Genomics** – the study of our genetic material, or DNA – is enabling truly personalised medicines, designed to effectively address particular patients' disease with as few side-effects as possible. It is also paving the way to more accurate, convenient diagnostic products that help characterise and potentially prevent disease, by picking up signs much earlier.

> The 21st century is proving to be one of the most exciting and prolific periods of innovation in biosciences and healthcare."

As engineers and biologists join forces to build ever-more sophisticated gene-editing tools, new classes of medicines are emerging, including **cell and gene therapies**. These involve altering cells or genes, usually outside the body, to provide a patient-specific therapy that is re-injected into the patient. Scientists' growing understanding of how genes exert their influence, and of the crucial impact of multiple environmental factors on those genes ("epigenetics"), is opening up new frontiers of drug research. It has led to an explosion of activity around the gut microbiome – the colonies of micro-organisms residing in our gut – and its role in health and disease.

Genomics, **engineering biology** and related data and analytics tools are also helping fuel innovative approaches to tackling pathogenic bacteria. These may provide new, more effective and less toxic medicines for a range of life-threatening infections. Importantly, they may also help address the growing global challenge of **antimicrobial resistance**.

UK bioscience companies are at the forefront of these innovative, converging disciplines. These companies are a key part of the UK Bioindustry Association (BIA)'s membership and as the trade association for innovative life science companies in the UK, the BIA provides a home for these groups through our Advisory Committees and working groups on antimicrobial resistance, cell and gene therapy, engineering biology and genomics.

Given both this focus of our membership and the increasing external interest in how these innovations can tackle key challenges that society faces and contribute to the growth of a 21st century economy, the BIA is delighted to publish this series of four explainers on antimicrobial resistance, cell and gene therapy, engineering biology and genomics.

Within these explainers, we describe what these areas are all about, the important contributions made by UK bioscience firms, and the external environment required to ensure that these innovative approaches continue to benefit patients, the economy and society as a whole.

I hope you enjoy reading them.

Steve Bates OBE
CEO, UK Bioindustry Association

# What is engineering biology?

The industrial revolution in the 19th century was a triumph of engineering, as humanity built machines to harness mechanical power from coal. The technological revolution, beginning in the 1980s, is a triumph of digital programming and smart gadget design. The Human Genome Project at the turn of the 21st century was a revolution in biology, laying out the genetic code of life – DNA.

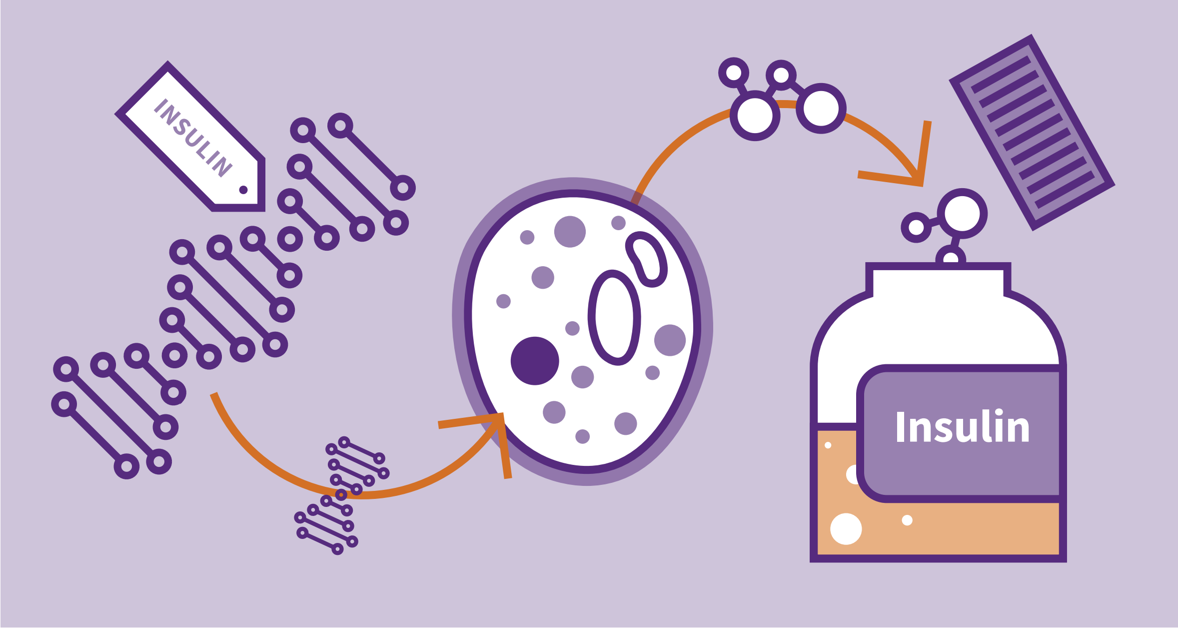
These advances have already transformed our world. The next revolution promises to do so again. It combines engineering, biology and programming to create tools, processes, products and organisms that are greener, cleaner, more efficient and more effective than ever before.

This is engineering biology. Its applications span medicine, agriculture, energy, manufacturing and almost every other industrial sector. UK companies are at the forefront of this engineering biology revolution. They're helping develop the engineering biology toolbox.

Scientists are already able to insert corrected copies of defecting or missing genes into patients with certain genetic diseases, with extraordinary results. Engineering biology tools are enabling more refined and efficient approaches. They include genome editing techniques that allow scientists to accurately and rapidly cut out, replace or repair very specific bits of genetic material (DNA), not just entire genes. One recently-developed tool, known as CRISPR-Cas 9 (short for 'clustered regularly interspaced short palindromic repeats and CRISPR-associated protein 9'), can be used like a pair of molecular scissors. It was inspired by a genetic defence mechanism found in some bacteria. Other engineering biology tools include molecular switches that turn particular genes on or off – likewise inspired by nature's own versions, called gene promoters.

Engineering biology (also called 'synthetic biology'), is industrialising DNA sequencing, manufacture and editing, making all of it cheaper and more accessible – rather like Microsoft Word did for text-editing. A new generation of software and systems are being built to support such work, within 'wet-dry' laboratories that contain both test-tubes and computers.

The products of engineering biology are as exciting as they are various. Across healthcare, they include genetically-reprogrammed mosquitoes that limit the spread of diseases such as dengue fever; immune-system cells tweaked to accurately detect and kill invading cancers; gut bacteria harnessed to deliver targeted therapeutics and vaccines, and more.



Engineering biology is enabling efficient manufacturing of bio-degradable, renewable chemicals, helping reduce our reliance on petroleum-based products. It is re-programming bacteria to efficiently digest plastic drinks bottles. It is creating raw materials – including DNA, manufactured affordably, at-scale – with multiple further applications, from nano-batteries to digital data storage.

Engineering biology draws together experts from across very different academic segments, opening each up to new ways of thinking. Computer scientists, engineers, biochemists, molecular biologists and geneticists may be in the same team. This cross-disciplinary set-up generates huge numbers of new ideas, tools and potential applications.

Biologists take inspiration from processes and organisms found in nature. Together with computer scientists and engineers, they may design and genetically-programme systems that build upon nature's own to do new, useful things, such as mopping up harmful metabolites and pollutants, or fighting infection and cancer.

Engineers, meanwhile, may be drawn to DNA's structural properties – how it behaves given its physical shape, rather than the life-instructions encoded in its base-pairs. The DNA molecule, however long, is always about 2 nanometers wide. That nano-scale uniformity, coupled with an electric charge along the molecule, means DNA can be used as a scaffold for other materials. It can be made into gas-sensing nanowires, for instance, or into "quantum inks"- colour-coated DNA strands used to anti-counterfeit banknotes, passports or other secure documents. DNA may also be useful in nano-scale batteries, designed to efficiently harness the energy released from metabolic reactions similar to those that occur in our bodies every day.

Three-dimensional (3D) printing is another exciting tool emerging from engineering biology. Scientists are already able to grow new biological tissues (or repair existing ones) like cartilage or muscle, using cells, growth factors and an appropriate scaffold. This is tissue engineering, and involves a range of separate steps and processes, from cell extraction to scaffold-construction and assembly. 3D printing technology allows tissues to be printed out, layer by layer on a single device, using 'ink' made of appropriate cell culture media. One day, it may even be possible to print entire organs.

Some engineering biologists envision typing into a computer the instructions for a particular tissue or even organism, and watching it print out. We are not quite there yet. But 3D printing may, one day, bring about transformations similar to those triggered by the invention of the printing press in the 15th century.

# UK excellence in engineering biology

The UK is home to world-leading expertise and research across the biosciences, engineering and data science. Innovation within these disciplines is often clustered together within cities or regions, offering unrivalled opportunities to exchange skills and ideas. As engineering biology brings all these disciplines together, it is allowing the UK to be in the vanguard of this new revolution.

Engineering biology in the UK is already helping address some of the world's thorniest challenges, from industrial pollution and plastic waste to sustainable agriculture and infectious diseases. UK engineering biology companies are offering more than a suite of solutions; they are developing an industrial manufacturing platform unlike any other. It is driving clean economic growth and job-creation, in what is increasingly referred to as the "bioeconomy".

The UK government is intent on building the country's excellent science-base to form the world's most innovative economy. Its industrial strategy is focused on improving productivity by generating new ideas, creating highly skilled jobs and improving digital infrastructure to enable businesses to thrive all around the country. As part of this industrial strategy, innovative companies benefit from a range of support schemes and fiscal incentives, from R&D credits and the Patent Box, to new funding via the multi-billion Industrial Strategy Challenge Fund.

**223+**
companies

**£300+ million**
government investment

**1,300+**
employees

Recognising engineering biology as an area of strategic importance, the UK government established the Synthetic Biology Leadership Council in 2012. The Leadership Council brings together the Life Sciences Minister and other government representatives with senior industry and academic stakeholders to provide high-level engagement to boost the growth of the sector. The UK government also invested over £300 million into building a nationwide network of Synthetic Biology Research Centres.

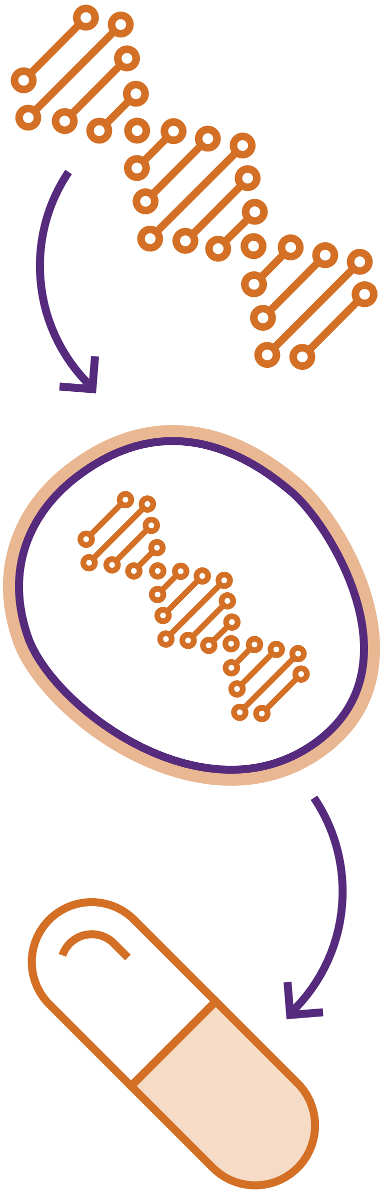
Each centre brings a distinctive field of expertise, from the engineering of bacteria to make useful products from greenhouse gases in Nottingham, to the development of the underlying tools needed to realise the full potential of engineering biology in Edinburgh. These centres are complemented by several DNA foundries, specialists in the assembly of DNA, and SynbiCITE, the UK's national centre for the commercialisation of engineering biology.

Together these centres of excellence and commercialisation connect academia and industry to form a thriving engineering biology community. And with London's financial centre continuing to draw in local and international investors, there are many opportunities to build a world-leading engineering biology business environment and the bioeconomy.

Over 223 companies in the UK and their 1300 employees are building tools, technologies and solutions with the potential to reduce or eradicate certain diseases, enhance pandemic preparedness, transform food and chemicals production and clean up waste and pollutants.

The enclosed case studies demonstrate how UK engineering biology companies can tackle disease, help solve some of society's most pressing environmental challenges and create new tools to underpin developments in bioscience. This is but a snapshot of the exciting innovation at work today. To discover more about the BIA's Engineering Biology community visit:

**https://www.bioindustry.org/bia-membership/advisory-committees/engineering-biology-advisory-committee.html**



# Harnessing engineering biology to tackle disease

**Prokarium and Chain Biotechnology are using harmless bacteria as mini drug- or vaccine-factories. The bacteria are engineered to carry the genetic instructions for helpful molecules into the gut, where the factories are switched on and the relevant protein or metabolite is made and delivered directly to where it can have the greatest effect.**

## Prokarium

London-based Prokarium is developing a new, more convenient way to produce and administer vaccines. Its approach may generate medicines that are cheaper to make and easier to store and distribute than existing, injectable vaccines. It may also expand the range of diseases that can be targeted. If successful, the technology could have a major impact on public health in many parts of the world.

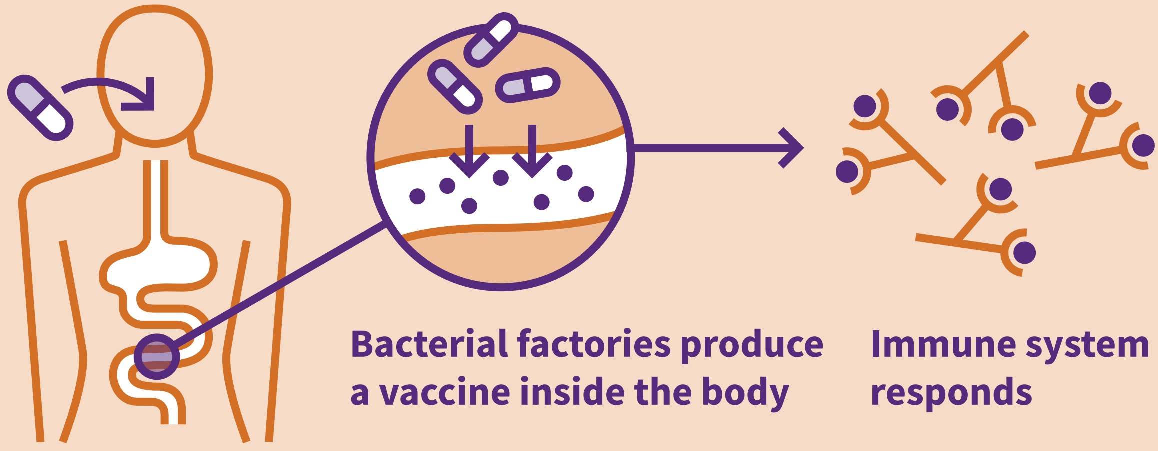
Prokarium's oral vaccine delivery platform uses a modified, harmless version of *Salmonella* bacteria to carry the genetic instructions for a vaccine to the site where it can have the greatest effect. The modified bacteria are swallowed in a capsule and pass through the stomach and into the small intestine, which is home to many important immune system cells and tissues. There, the vaccine (antigen) is expressed and triggers a powerful immune response. (*Salmonella* are potent immune-system stimulators already, so no other substances – adjuvants – are required to boost their effect.)

Prokarium's lead programme is a vaccine against typhoid fever, and the related para-typhoid strain, which affects an estimated 27 million people each year, causing over 200,000 deaths.

Even when vaccines are available for a given disease (there is no vaccine for para-typhoid fever), they can be expensive and time-consuming to manufacture and don't always reach those in need. Most vaccines are proteins that are administered by injection, requiring a specialist nurse or doctor, and increasing contamination risk. Some vaccines must be refrigerated to remain active, presenting distribution challenges in some regions.

Prokarium has developed a way to ensure its vaccines remain viable for several weeks at temperatures up to 40 degrees centigrade. The company claims that its *Vaxonella* platform could halve manufacturing and distribution costs, significantly increasing the number of people who can access vaccines. *"The vaccination approach to typhoid and para-typhoid is very important from a global health perspective,"* says Ted Fjallman, Prokarium's CEO. Many of those suffering from these illnesses are currently given antibiotics. This exacerbates the global anti-microbial resistance challenge.

Prokarium's typhoid vaccine candidate has been safely dosed to nearly 500 volunteers during Phase I and Phase II clinical trials. The company plans a dual typhoid-parathyroid vaccine, and is also working on a vaccine for chlamydia,




the most common sexually-transmitted infection in the world, for which no vaccine exists today.

Prokarium's method of delivering small biological vaccine factories to the target site allows it to produce and deliver highly complex molecules *in situ*, skirting the challenges of producing these compounds outside the body, and of getting them safely and intact to where they're needed.

In February 2018 Prokarium raised $10 million from international investors. In May 2018 the company moved into the London Bioscience Innovation Centre near King's Cross in London, where it is expanding its R&D team.

"There are trillions of microbes in the human gut which play a pivotal role in health and wellbeing."

## CHAIN Biotechnology Ltd.

CHAIN Biotechnology is a privately-held microbiome company, based in Marlow, UK, developing technology to restore metabolic imbalance in the gut but also to enhance delivery of molecules to relevant targets in the gut that are difficult to reach via more conventional delivery mechanisms. CHAIN collaborates with the Synthetic Biology Research Centre at the University of Nottingham, led by Professor Nigel Minton, a world-leader in clostridial gene technologies and, to date, has raised approximately £3M from equity investment and grant support from Innovate UK.

CHAIN use harmless *Clostridia* bacteria as mini drug factories in the gut. Clostridia are one on the main groups of microbes naturally found in the gut where they breakdown dietary fibre and produce short-chain fatty acids that keep the lining of the colon in good shape. CHAIN has assembled a team of *Clostridia* experts to engineer the bacteria to produce useful metabolites and biologics that confer further health benefits. The genetic instructions for production of each bioactive are hardwired into the chromosome and only switched on during growth in the gut. This supports direct delivery of the bioactive to where it can have the greatest effect.

CHAIN's lead product is a candidate for inflammatory bowel disease (IBD). *Clostridia* are engineered to produce a metabolite called beta hydroxybutyrate (BHB) that reduces inflammation. This metabolite is produced naturally in the liver

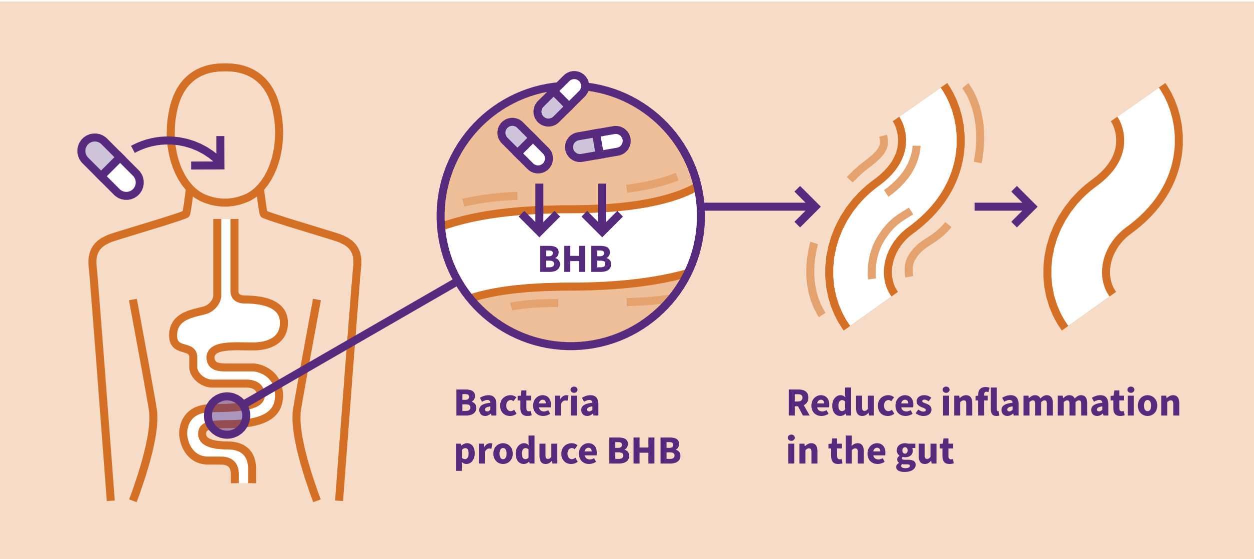
> CHAIN has assembled a team of *Clostridia* experts to engineer the bacteria to produce useful metabolites and biologics that confer further health benefits."

during fat metabolism, but it not normally found in the lumen of the gut. CHAIN has demonstrated the efficacy, production and gut delivery of BHB using a variety of *in vitro* and *in vivo* models.

CHAIN's *Clostridium* based platform for assisted drug delivery, referred to as CADD, supports the production and delivery of a wide range of bioactives including metabolites, peptides and enzymes and works with partners to develop additional products.

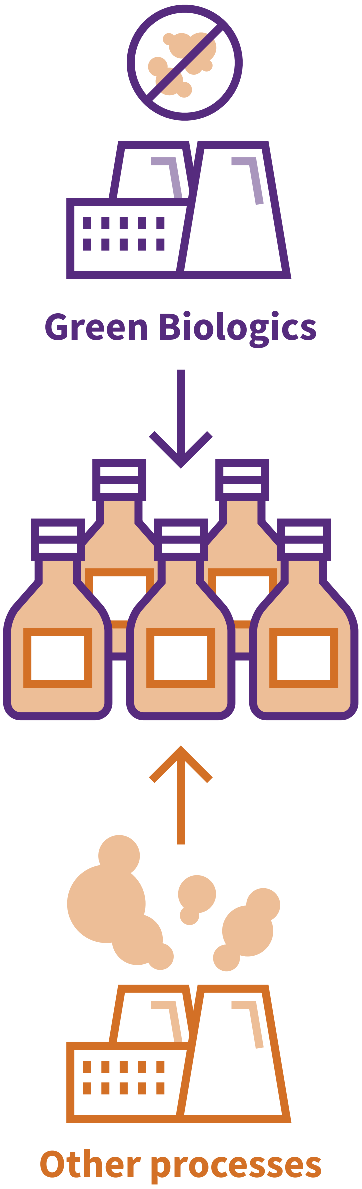
Cleverly, the engineered strains also form spores – dormant, seed-like forms of the bacteria, protecting them from unfavourable environmental conditions. The spores, formulated into tablets, are swallowed and survive the acidic stomach before germinating in the lower part of the intestine, a *Clostridium*-friendly anaerobic (oxygen-free) environment. There, they replicate and produce the helpful bioactive. Unlike most biologics, spores do not require any cold storage and have a long shelf live. This Trojan-horse approach to drug delivery also overcomes many of the difficulties in delivering effective therapeutics to the lower gut, notably the risk of degradation in the stomach and absorption in the small intestine. CHAIN's approach also circumvents the need to purify the bioactive in advance of delivery which significantly reduces cost.

CHAIN's technology has the potential to be highly disruptive both in terms of cost but also efficacy for both the treatment and prevention of chronic and debilitating gut related diseases, and also for a range of other diseases linked to disturbances in the gut microbiome.



# Harnessing engineering biology to tackle environmental challenges

**Green Biologics is using bacteria to sustainably manufacture renewable chemicals which are currently commonly made using petroleum oil and used in a wide range of products. CustoMem has developed a bio-based material that removes targeted harmful chemicals from industrial waste-water. Both technologies reduce our environmental footprint for a more sustainable economy.**




## Green Biologics

Oxfordshire-based Green Biologics is engineering biology to manufacture cleaner, more sustainable specialty chemicals, used to make a wide range of products, from pharmaceuticals and cosmetics to paints and plastics.

Chemicals such as n-butanol and acetone are currently made most efficiently, and cheaply, from petroleum oil. Yet some bacteria produce these chemicals naturally; indeed, up until the 1950s, fermentation was the standard manufacturing procedure.

Green Biologics has selected and evolved strains of *Clostridia* bacteria that are particularly good at making n-butanol and acetone, creating an efficient, high-yield fermentation process that avoids the high environmental cost of hydrocarbon-based manufacture. The company produces these bio-based chemicals commercially at a plant in Minnesota, in the United States.

Green Biologics is also using a gene-editing technology, CLEAVE, to make changes to its chemical-producing *Clostridia* microbes even more specifically. For instance, it can change the type of feedstock the bacteria use, and/or the chemicals that they produce. The company's deep expertise around *Clostridia* means *"we can integrate new genes to programme the bug to make an entirely new product, at high yields, including products that it would not make naturally,"* explains Chief Technology Officer Liz Jenkinson. *"We have this great industrial strain [of Clostridium] that is now a chassis host for whatever we want to produce."*

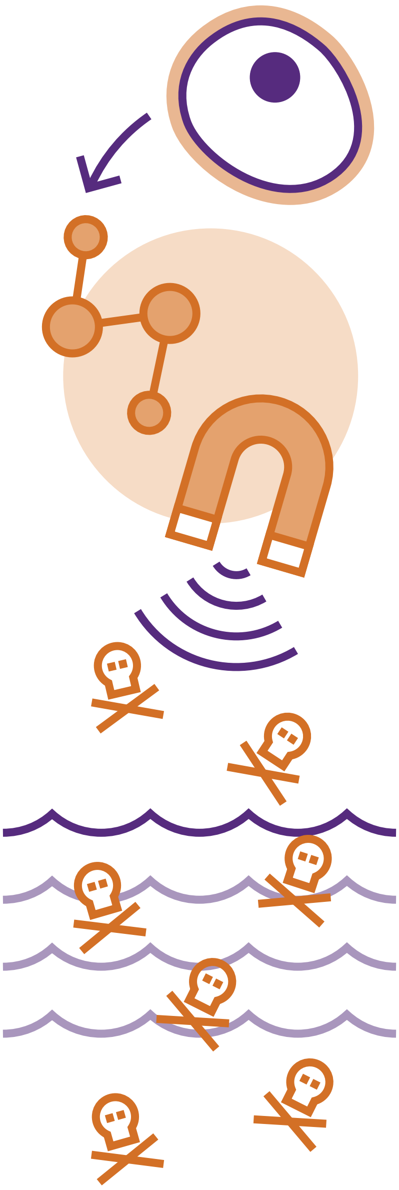
The potential scope of this technology is huge, enhanced by the native bacterial CRISPR-Cas gene editing system and other, increasingly accessible and efficient gene editing tools.

Green Biologics knows that being green in itself is not enough for commercial success – notwithstanding consumers' growing appetite for sustainable materials. But it believes its products will ultimately compete with petro-chemical based approaches. For instance, the company's fermentation-produced chemicals may contain lower levels of certain contaminants, offering cost and efficiency advantages in downstream formulation and chemical synthesis processes.

*"We focus on chemicals whose current production methods allow us to compete and gain an advantage,"* says Jenkinson.

Green Biologics' partners have already launched a sustainable nail polish remover using plant-derived acetone, and a natural, bio-based charcoal lighter fluid. The company's butanol has also been used to make a bio-based dry cleaning solvent. For now, these products are produced in the United States by Green Biologics. But *"there's a lot of interest in our products in Europe too and we are selling them on a global basis,"* says Jenkinson.

Green Biologics was founded in 2003 by serial entrepreneur Edward Green, also founder and CEO of Chain Biotechnology. It is funded by venture capital and grants.



## CustoMem

Through strong expertise in engineering and biochemistry, CustoMem has created a novel material that can selectively and efficiently remove dangerous chemicals from industrial waste-water. CustoMem Granular Media (CGM) is a bio-based material and can be customised to bind some of the most polluting, resistant artificial substances. It does so in a manner that allows both the material, and the pollutants it removes, to be recycled.

Each day, the global manufacturing industry produces millions of tonnes of water contaminated with fluorinated substances (formally, Per and polyfluoroalkyl substances, PFAS). These chemicals are used to make water-proof, dirt-resistant clothing, non-stick coatings, fire-fighting foam, and more. But while their utility makes them increasingly widespread, these substances are non-biodegradable. They persist and accumulate in the environment, and in our bodies, sometimes with harmful effects.

Current methods used to remove fluorinated substances from water, such as granular activated carbon or ion-exchange resins, are not particularly selective for these chemicals, which are, at a molecular level, part hydrophilic (water-loving) and part hydrophobic. The standard methods also generate large volumes of waste which must be disposed of. Since fluorinated substances are heat resistant, the waste typically goes through very high-temperature (1100 C) incineration and uses lots of energy, contributing even more to its large carbon footprint.

CustoMem's Granular filter Media includes molecular binding domains that specifically capture the target chemical. The binding domains are identified using high-throughput screening of billions of possible structures, rather like target screening in drug discovery. The chosen domain is then combined with a cellulose-based bio-material that has been adapted for use in industrial water.

Importantly, CGM is designed to operate in the steel tanks currently used by industry for treating water, and to be re-usable. *"We can regenerate this granular media using a safe, aqueous wash, rather than having to dispose of it once it is saturated with pollutant,"* explains CEO Henrik Hagemann. That is an important advantage, given the costs and Health & Safety liability of hazardous waste disposal. The pollutant it collects can also be recycled: CGM captures particular substances in a highly concentrated form that's ideal for some manufacturing applications – yet expensive to produce, and to buy. (CustoMem is a member of the Ellen MacArthur Foundation Circular Economy 100 where they are coordinating a feasibility project around reuse of fluorinated substances called PFAS, assembling innovators that contribute to a more sustainable economy where materials are re-used).

> CustoMem's technology has already attracted large industrial players, facing increasingly stringent waste-regulations."

As CGM is uniquely tuned for specific PFAS, the regenerable granular media is able to capture the same flow rate of contaminated water as existing media, but in a much smaller tank. This opens up opportunities on industrial sites where space is limited.

The UK start-up, spun out of Imperial College London, has raised £1.5 million to date from its founders and through grants. CustoMem's technology has already attracted large industrial players, facing increasingly stringent waste-regulations. The company has completed trials with a German airport and with a UK fire-fighting foam maker, comparing CGM to activated carbon and ion-exchange. Both potential clients want to progress to testing the media on their own sites. CustoMem has also signed materials transfer agreements for feasibility tests with two of the world's largest players in the water sector.

# Harnessing engineering biology to create new tools for bioscience

**Synpromics is engineering custom-made gene switches; Toughlight Genetics is engineering enzymes to quickly and cheaply produce DNA. Both technologies have a wide range of applications, from enabling more efficient cell and gene therapies and advanced therapeutics, to the development of smart materials and the storage of data.**

## Synpromics

Edinburgh-based Synpromics designs and builds switches that turn particular genes on or off in specific conditions. This provides a powerful way to control gene expression and is central to gene and cell therapy development.

In nature, "promoters" are DNA sequences that sit alongside individual genes and control when, and how much of, that gene's uniquely-encoded protein is made. Natural promoters have evolved to regulate gene expression in particular physiological settings.

Synpromics' synthetic promoters are tailored to control gene expression far more precisely, in very specific circumstances, in order to achieve a desired outcome.

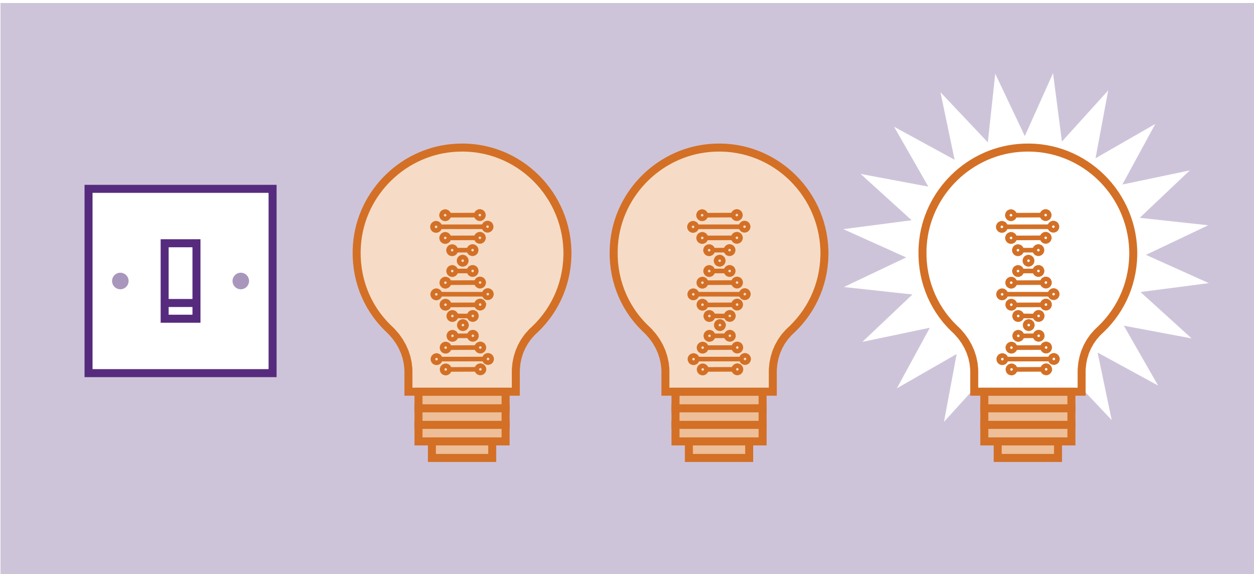
For example, the company can make promoters that work only in certain tissues, such as the liver, to efficiently generate high levels of a particular protein. This level of specificity and efficiency is very useful in gene therapy, where corrected copies of particular genes are delivered to patients to replace missing or dysfunctional proteins or processes. Tighter gene expression control could allow lower doses and improved safety.

Furthermore, Synpromics can make promoters that are smaller than those in nature, by singling out the critical elements required for protein production. This helps overcome size constraints on gene therapy delivery and uptake. The carrier molecules, typically viruses, used to deliver DNA into patients can only carry a limited amount of genetic material.

Working out which parts of natural gene promoter sequences are key to protein production in a given tissue or organ is complicated. Scientists are only just beginning to unpick the complex web of genome regulation and the multiple influences on it. Synpromics' team includes bioinformatics experts and data scientists able to integrate and interrogate a range of data sources to generate informed predictions about gene regulation in specific conditions.

Synpromics' gene-switch design capabilities have attracted over a dozen academic and industrial partners working in cell or gene therapy. The company's promoters are patentable, thanks to their unique DNA sequences, making them *"very much part of the [gene or cell therapy] product"*, clarifies founder and Chief Scientific Officer Michael Roberts. Reflecting that, the company is in line to receive clinical development milestones and sales royalties on partners' eventual therapies.

Manufacturing is another important application for synthetic promoters. Synpromics is investigating ways to enhance the production of carrier viruses for gene therapies, but also to boost the manufacturing efficiency of biopharmaceutical products, such as monoclonal antibodies. The company is partnered with Lonza, one of the world's leading biologics manufacturers, to improve the productivity of certain strains of Chinese Hamster Ovary (CHO) cells used to make proteins. Biopharmaceuticals are the fastest-growing category of medicines, and include some of the most valuable, and expensive, therapies. Boosting CHO productivity would cut the time and cost required to make these drugs, potentially leading to greater access and lower prices.



## Touchlight Genetics

> Touchlight Genetics uses engineered enzymes to rapidly and accurately amplify, or copy, any given DNA sequence."

DNA is the fundamental component underpinning the engineering biology revolution that is changing medicine, manufacturing, and more. Finding quick, efficient and reliable ways to produce DNA is therefore critical. Traditional DNA-production methods involve growing bacteria that contain little loops, or plasmids, that include the required DNA sequence. These fermentation techniques have evolved, but remain time-consuming, inefficient and error-prone.

Touchlight Genetics is one of several biotech companies seeking to transform DNA synthesis and amplification. The company uses engineered enzymes to rapidly and accurately amplify, or copy, any given DNA sequence. Its resulting 'doggybone' constructs – named for their shape – are closed-ended double-strands of DNA, which can be manufactured at commercial scale within two weeks, rather than the months required for plasmid DNA production. The doggybones are stable, reliably reproduce the DNA sequence of interest, and don't contain any superfluous material. This means they avoid some of the safety concerns surrounding plasmid DNA, such as antibiotic resistance genes used for plasmid selection.

These characteristics make Touchlight's doggybone DNA a useful substrate for cell and gene therapies. These therapies typically use modified viruses – tiny protein-encased packages of nucleic acids – to deliver a corrected copy of a gene directly to patients (gene therapy), or into cells that are subsequently administered as cell therapy.

But doggybone DNA also opens the door to a new generation of gene therapies, according to Touchlight's founder and CEO Jonny Ohlson. *"We're an enabling technology for the current, first wave of gene therapies. But we're moving, longer-term, into non-viral gene therapies and also vaccines where the DNA is the product, in its purest form."*

For now, viruses remain the most popular DNA delivery vehicles, since they're naturally good at invading cells and delivering their payload. But they're not perfect. They contain material beyond the DNA or gene of interest, which may be harmful. Hence scientists are indeed exploring various non-viral methods of gene-delivery, seeking to increase their purity and scalability.

Touchlight is working with pharmaceutical and biotech companies to explore applications for its doggybone DNA. Yet those potential applications extend beyond new generations of therapeutics and vaccines, and even beyond medicine. DNA is an extraordinary molecule. Alongside its life-giving genetic codes, it also has interesting material and chemical properties. These present opportunities to develop "smart" materials that respond to changes in their environment, or even harvest energy. DNA's code-carrying capacity can also be exploited to store vast amounts of other kinds of data, at very high density in tiny spaces.

In preparation for the DNA-driven future, Touchlight already has a Good Manufacturing Practice (GMP) DNA production facility and brand-new laboratories at its West London base, on the site of the historic Hampton Water Works. The company has raised £20 million since its founding in 2008.

# What next?

Engineering biology has already created more than 1,300 highly skilled UK jobs and the companies are attracting significant investments and M&A deals. Recent deals include Bristol spin-out Ziylo being bought by Novo Nordisk for $800m, while Cambridge-based Quethera was acquired by Astellas Pharma for £85m. The sector has the potential to do even more in the future – some are even talking about a not so distant future where the UK is home to the Google or Facebook of engineering biology. But various efforts are required to catalyse the growth of the sector.

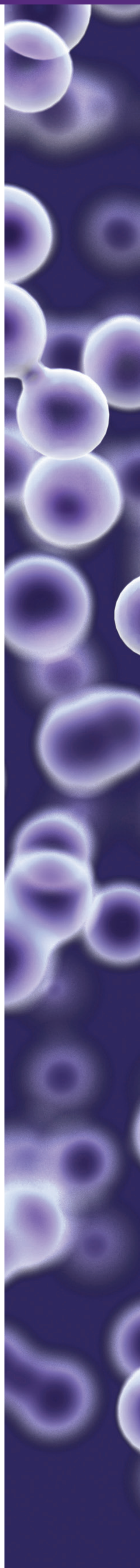
As engineering biology is not a single area of research, it has, arguably, struggled to establish itself as a "brand". Perhaps paradoxically, the many applications of engineering biology make it difficult to communicate its impact. While policymakers have identified its strategic importance to the UK, greater engagement is needed to foster a transparent dialogue between the public, scientists, engineers and policymakers. An important part of this dialogue is addressing concerns of how engineering biology research is carried out. Innovation should never come at any cost and responsible innovation is a priority of the whole engineering biology community.

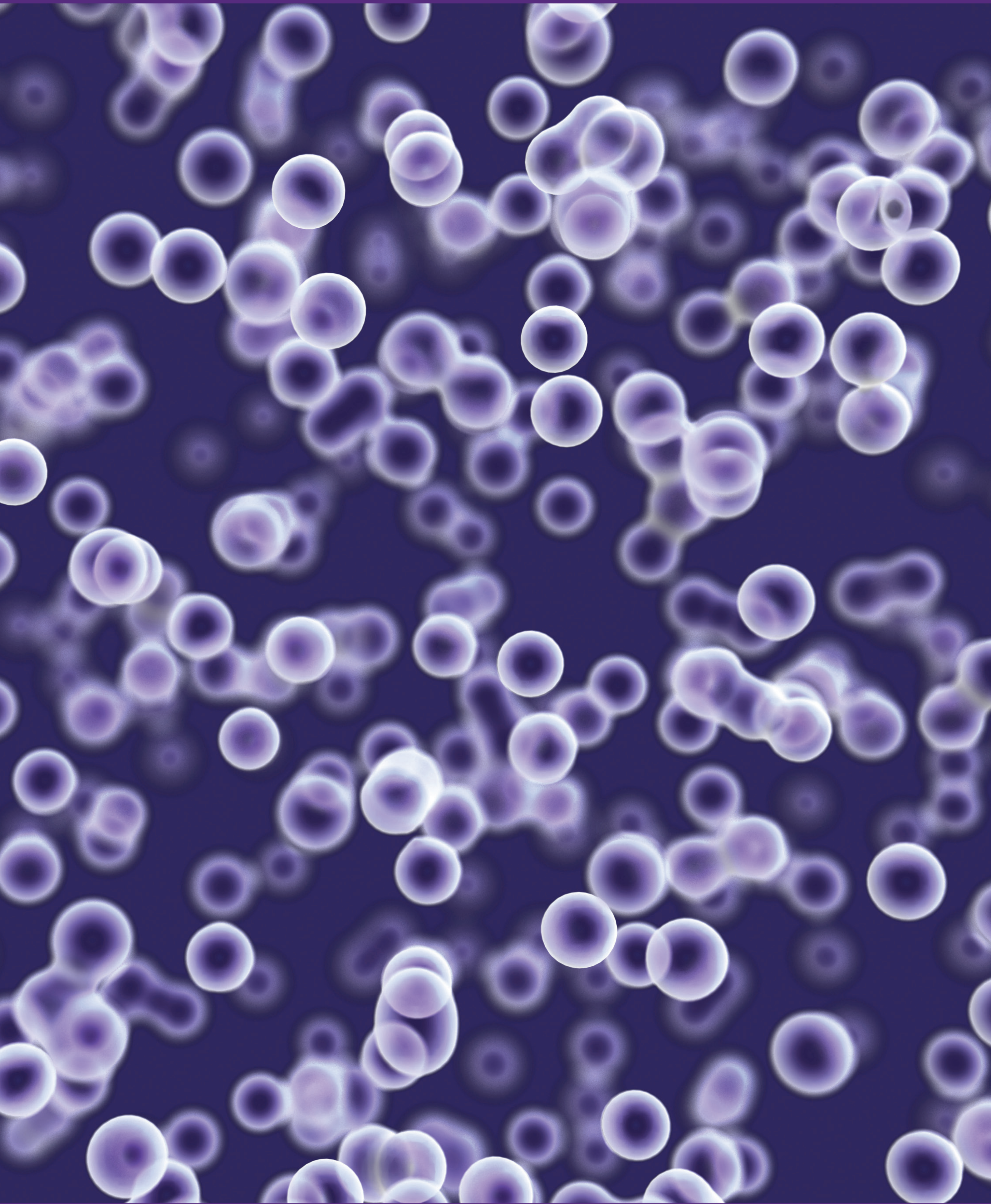
Engineering biology's difficulty to establish itself as a recognisable brand also needs to be addressed to successfully build a broad expert workforce. The work of the national research centres, the leadership of the Synthetic Biology Leadership Council, and UK universities' and high schools' participation in the international engineering biology competition iGEM are all important efforts to communicate the many career opportunities in the field to prospective post-grads and PhDs.

While the UK's world-leading academic science-base and national network of centres of excellence generate ground-breaking ideas, there has been an ongoing challenge of how best to commercialise these ideas. The engineering biology community continues to work hard to build entrepreneurial spirit into the universities, with the aim of enthusing young innovators to spin their ideas out of academia and turn them into profitable products and applications that will both solve societal challenges and deliver sustained benefits to the economy. For this to happen, students need to learn and get excited not just about science, but also about how to build and manage a bioscience company. Several industry-led programmes are doing just this by introducing science students to the world of business, including the BIA's PULSE programme.

As with most revolutionary technologies, it is start-ups and small to medium-sized companies that will keep pushing the boundaries of engineering biology. The UK is one of the best countries in the world to start and grow innovative businesses, with a strong intellectual property framework and fiscal benefits, such as R&D tax credits and the Patent Box. The UK government is committed to building on this supportive business environment to raise research and development investment to 2.4% of GDP by the year 2027 and 3% in the long-term. With the newly formed UK Research and Innovation, incorporating both the Research Councils and the business-focused Innovate UK, the UK's funding system is well placed to deliver on that promise. But to grow the engineering biology sector further, long-term focused funding is needed. This requires the engineering biology community and government to work together. If we get it right, we will transform society.

From tackling disease to generating clean growth, engineering biology is already placing the UK at the forefront of the solutions to global problems, including many of the world's sustainable development goals, as set out by the United Nations. UK companies are innovating solutions to environmentally harmful wastewater, previously unstoppable mosquito-borne diseases and the vast amount of plastic waste littering our oceans. They are concentrating the power of artificial intelligence (AI) and machine learning to the complexity of biology to help us use nature even more efficiently. They are harnessing the power of nature to create a healthier and cleaner society. This is what engineering biology is all about. This is the next revolution.





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