Manufacturing stories

A celebration of innovation in manufacturing

THE ROYAL SOCIETY

Contents

Introduction from the Royal Society	3
Synthesising sustainable polymers	4
Making glass with low-carbon fuels	6
Building a hydrogen future	8
Redesigning the car	10
Decarbonising concrete	12
Avoiding weather-related disputes	14
Automating stone cutting	15
Digitalising design for manufacture	16
Sorting nuclear waste	18
Reducing food waste	19
Replacing plastic with seaweed	20
Creating bottles from wood pulp	22
Optimising insect protein production	24
Farming salmon sustainably	26
Automating vertical farming	28
Extracting collagen from jellyfish	30
Producing nucleic acid medicines	32
Manufacturing oligonucleotide medicines	34
Building nuclear power plants	36

Sir Adrian Smith

President of the Royal Society

"The spirit of innovation is alive and well in labs, manufacturing sites and offices all across the UK."

The UK has a fine tradition in manufacturing, driven by the power of people and ideas. Today the UK will not be competing on cheap labour, nor on our ability to dig natural resources out of the ground. Our competitive advantage is our ability to innovate. Innovation is central to increasing productivity and in driving the UK's long-term growth and wellbeing.

Fortunately, as you can see in the stories told in this booklet, the spirit of innovation is alive and well in labs, manufacturing sites and offices all across the UK. And these are not stories of growth driven solely by consumption and the pursuit of growth as an end in itself, these are stories of sustainable growth and societal benefit.

You can read about more efficient and novel food production and new techniques not only for the creation of new materials, medicines and vaccines but also in how we can manufacture them efficiently at scale. There is the development of technology to use low carbon fuels and crucially how we put them to work in everyday situations in the real world. There is also greener packaging and construction, and the use of greater digitisation of processes to drive efficiency.

Among these innovators there are university spin-outs, collaborations and industrial giants. There are new products, new takes on existing ones, new applications and also new processes. All of these are crucial to an innovation driven economy and we need to ensure that we have the skills, support and funding to ensure that the examples in these pages are just the tip of a large iceberg.

It has been said that if we do not get smarter, we will get poorer and that is undoubtedly true but we also need to focus on making the most of the creativity and ideas that are already out there. This publication is a celebration of innovation and there is much to celebrate but there is always more that can be done. We all have to strive to ensure that we continue to build on success, now and into the future.

Synthesising sustainable polymers

Professor Jason Chin FMedSci FRS, Chief Scientific Officer, Constructive Bio.

Professor Jason Chin is Chief Scientific Officer of Constructive Bio, a spin-out launched in 2022 from the Medical Research Council Laboratory of Molecular Biology based in Cambridge. Developed over 20 years of R&D, Constructive Bio now has the capability to manufacture novel synthetic polymers from living bacterial cells as bio-factories using sustainable and non-fossil materials. It will use these technologies to biosynthesise new classes of enzymes, pharmaceuticals, and biomaterials.

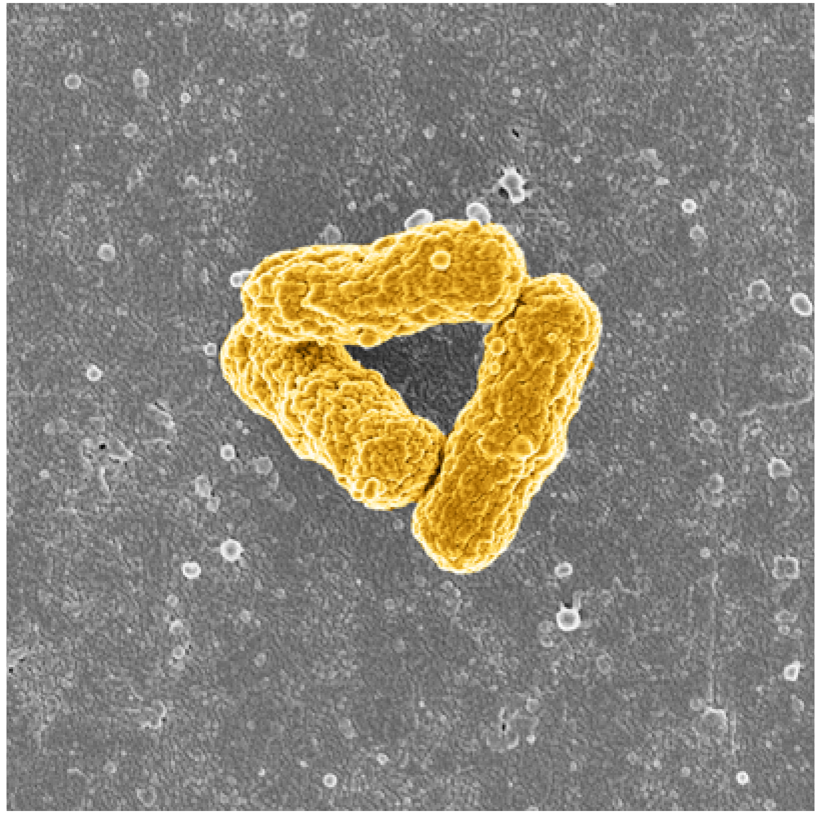
Major scientific advances were required to enable Professor Chin and his team to reprogramme the genetic code of living organisms. First, they built an entirely synthetic bacterial genome of four megabases from chemically synthesised DNA. This genome uses a subset of the 64 naturally occurring DNA codons to code for the twenty common amino acids required for life, freeing up the remaining codons to code for alternative molecules other than amino acids. Second, they engineered new translational machinery to take advantage of these freed codons. This required making new transfer RNA and synthetase enzymes to recognise the freed codons and pick up and carry specific molecules from within the cell. Last, they engineered new ribosomes, the platforms upon which synthesis happens, to join the molecules to form polymers. This means that cells can now be programmed to manufacture polymers, composed of specific molecules linked in a defined order, by the addition of synthetic DNA.

The new synthetic system works in parallel to the natural equivalent, allowing the bacteria to live on low carbon sustainable feed, whilst also acting as a platform to manufacture novel polymers which could be used for a range of products such as medicines or biodegradable plastics. These synthetic bio-factories also have advantages over using naturally occurring cells for production, such as inbuilt resistance to viruses which can contaminate cultures and reduce bio-manufacturing yields.

With the ability to construct polymers not found in nature, Constructive Bio also aims to ensure that any novel polymer produced can be degraded back to its monomer constituents, and where necessary they will create pathways to convert polymers back to their monomers. These monomers can then be recycled into new polymers which avoids the environmental buildup of new polymers.

Constructive Bio is currently in the process of scaling and commercialising the designed technologies, and holds significant potential to build the sustainable industries of the future.

> “This innovation in manufacturing was facilitated by the long-term funding provided by the MRC Laboratory of Molecular Biology in Cambridge, and a supportive investment community for commercialisation.”



Images:
Professor Jason Chin FMedSci FRS and an example of a synthetic cell.

Making glass with low-carbon fuels

Richard Katz, CEO and Founder, Glass Futures.

The use of fossil fuels in glass furnaces releases significant quantities of greenhouse gases. Glass Futures, a Research Technology Organisation, was set up to bring industry and academia together to identify ways of decarbonising the production of glass bottles, float glass for windows and glass-fibre. In 2020, Richard and his team received Government funding to start a programme investigating the potential of alternative low carbon fuels in glass furnaces.

The programme tested a variety of low carbon fuels, including hydrogen, liquid biofuels and green electricity hybrids, for large scale glass production on an industrial test bed. The trials showed that using liquid biofuel produced from waste materials, such as used cooking oils, resulted in a carbon footprint reduction of 90% for bottle manufacture and approximately 80% reduction for float glass production. These achievements attracted interest from leading glass manufacturers and their major brand customers across the globe.

Richard and his team now partner with existing glass manufacturers and their supply chains to understand their manufacturing process and how they could utilise alternative sustainable energy sources. A new glassmaking pilot facility, the Global Centre of Excellence, is currently under construction in St Helens and is due for completion in early 2023. This facility will allow industry and academia to continue to test new technologies, and enable further research into decarbonising not only glass, but other industries such as ceramics and steel.

“A Royal Society conference I attended a few years ago introduced me to a senior Government Minister who understood the needs of the glass and other foundation industries. Without this connection, Glass Futures may never have got off the ground”

Above:
Glass Futures working with glass manufacturers to understand their process and how they could utilise alternative sustainable energy sources.

Building a hydrogen future

Lord Bamford, Chairman, JCB.

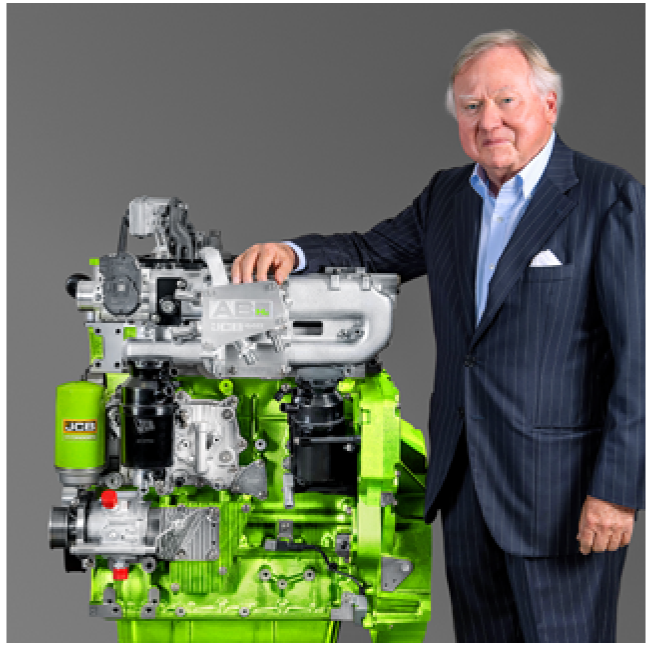
The construction industry needs to reduce its reliance on fossil fuels if the UK is to meet the 2050 net zero target. Realising the importance of zero carbon technologies, in July 2020, JCB started designing an engine for a digger than runs solely on hydrogen. By December that year they had a working prototype of the construction industry's first ever hydrogen powered engine.

Countries are increasingly in need of low carbon construction as the world's population continues to grow. To meet this demand, JCB recognised that they needed to utilise zero carbon technologies. Current electric construction machines, whilst better for the environment, are unsuitable in an isolated setting due to the limitations of battery charging infrastructure. Realising an alternative energy source to batteries was required, JCB began experimenting with the use of hydrogen.

Hydrogen fuel-cell technology was initially investigated. However, fuel cells are expensive and easily impaired by dust and volatile organic compounds found in tar and paint, making them impractical for use in construction. Knowing that customers wanted a machine that acted no differently to those already in production, Lord Bamford challenged the team to design an engine running purely on hydrogen gas.

A major challenge was re-designing and re-engineering the combustion process to use hydrogen efficiently and cleanly. Unlike petrol and diesel, hydrogen combustion operates at much lower temperatures and pressures making it unsuitable for use in traditional fuel engines. JCB collaborated with universities on engine design and, through a series of computer modelling iterations, perfected the mixing of air and hydrogen for consistent combustion. Customised spark plugs were then deployed to ignite the mixture. The result is a combustion engine designed from first principles running solely off compressed hydrogen gas. It is refuelled in the same way as a traditional engine, but instead emits only steam.

Diggers powered by hydrogen combustion engines are designed to be affordable products which can be adopted quickly in existing construction sites across the globe. As customer confidence in the use of hydrogen gradually increases, the next challenge will be manufacturing enough sustainably produced hydrogen to meet global demand.



"Having a leader with an entrepreneurial mindset gave JCB engineers the confidence to develop a new world first technology."

Images:
Lord Bamford, Chairman of JCB, with the JCB hydrogen combustion engine (left); and (above) JCB hydrogen-powered construction vehicles.

Redesigning the car

Hugo Spowers MBE, Managing Director, Riversimple Movement Ltd.

For Hugo Spowers, achieving sustainable automotive transport requires not only zero carbon technology, but a rethought business model for car use and ownership. There is currently no incentive for manufacturers to prioritise sustainability when their current revenue is based on car sales and replacement of parts.

Two core innovative principles are key to the development of a sustainable, low carbon footprint consumer car. Firstly, the car needs to be designed at a system level where the system, rather than the components of the system, is optimised for a new propulsion method. Second, in order to align incentives for car makers with sustainability requirements, there needs to be a new business model that makes sustainability profitable.

Hugo's team have removed redundant systems and designed a car using lightweight, high-quality materials, with the lower component count translating to increased reliability and longevity. Their current proof of concept two-seater car has electric motors in each of the four wheels, and is powered by hydrogen fuel cell technology which emits nothing but water.

Each powertrain component is connected, and energy can flow in either direction on any path, except back to the fuel cell. As the car slows down, supercapacitors cope with the rapid charge supplied by all-wheel regenerative braking, but do not store a lot of energy. Instead, this energy flows back to the motors and provides the power for fast acceleration.

The vehicles are not designed to be sold. Instead, a new business model has been designed which supplies the car to the driver through an all-inclusive package covering fuel costs and upgrades for the contract duration. By paying for all fuel costs, the priority for Riversimple becomes efficiency and durability of the car, ultimately aligning business profitability with low environmental impact.

"Being in the UK gives us access to an excellent network of technical companies connected to the auto, motorsport and aerospace sectors."

Images:
Proof of concept car, built to showcase a new business model for car ownership.

Decarbonising concrete

Dr Natasha Boulding, CEO and co-founder, Low Carbon Materials.

Low Carbon Materials (LCM) was founded by three Durham University PhD graduates who were motivated to reduce the carbon footprint of the construction industry. Their leading product, OSTO, is a gravel-like aggregate material made from waste ordinarily destined for disposal or incineration, and can be used to replace traditional, carbon-intensive aggregate found in concrete.

Concrete is the most globally used material after water, but it comes with a significant carbon cost. Dr Natasha Boulding and her team are tackling this with OSTO, a carbon-negative lightweight aggregate made primarily from plastic waste that would otherwise be incinerated, releasing large quantities of greenhouses gases. By using OSTO, the production of traditional, carbon-intensive concrete blocks can be made carbon neutral, reducing global carbon emissions.

Natasha and her team work directly with concrete manufacturers on an individual basis to develop a unique concrete mix design that is compatible with their existing manufacturing processes. They aim to produce OSTO commercially later this year, and in the long term they hope to create an entire portfolio of product-based solutions for the building materials sector.

> "Early on in LCM's timeline we met a Royal Society Entrepreneur in Residence at Durham University. He was instrumental in our development; his input helped us believe in what we were doing and recognise the potential in the built environment for low-carbon alternative materials."

Images:
Dr Natasha Boulding, CEO and co-founder of Low Carbon Materials (top right), and members of the team working on the production of OSTO.

Avoiding weather-related disputes

Josh Graham, CEO, EHAB.

Adverse weather conditions can severely delay expected project completion timelines in the construction industry. Currently, contracts between client and contractor determine how these delays can be compensated, but this can lead to long and costly legal disputes if the severity of the weather conditions experienced cannot be agreed on.

Josh Graham identified this problem when attending sessions coordinated by the Digital Catapult which brought together startups and industry leaders from the construction sector. EHAB have since developed a platform, the Weather Ledger, aimed at reducing the time and cost of weather-related disputes.

The platform first collects weather data at a hyperlocal site using weather satellites, before transferring this to a digital 'smart contract' using software code based on blockchain technology. The blockchain technology prevents the possibility of data tampering and the 'smart contract' enacts the pre-agreed terms automatically.

While the underlying technology is already commercialised, the Weather Ledger itself is at the pre-scale up stage and is expected to be commercially available within the next two years.

Above:
EHAB is working to resolve compensation disputes that arise from construction project delays due to adverse weather.

Automating stone cutting

Ross Horrigan, Technical Director, Loop Technology Ltd.

In collaboration with the University of Sheffield Advanced Manufacturing Research Centre, Loop Technology has developed a robotic paving unit cutting process which improves the efficiency and speed of paving cutting in town centres.

Growing demand for pedestrianisation has led to urban environments in the UK needing new paved areas. To cut stone paving which fits within set boundaries or around common street objects, pavers cut stone blocks to shape manually on site. The chief concerns with this method are the environmental impacts of noise pollution, slurry runoff and waste from stone offcuts.

Ross Horrigan's team have launched the IntelliPave project which addresses these problems by moving the cutting to an automated facility where noise, waste, and offcuts can be managed and recycled. The enabling technology is the integration of light detection and ranging (LiDAR) into consumer mobile devices, which has enabled the development of an app the pavers can use to generate miniature site surveys of the final paving design. This data can then be sent to the facility and used to automate the cutting of blocks.

The application of data collection and use of cutting automation on stone is new to the construction industry, but will lead to benefits in use of materials, logistics and impact on the environment.

Right:
Example of drain covers which require paving to be fit around these complex shapes.

Digitalising design for manufacture

Andrew Peters, Managing Director, Siemens Digital Industries Congleton.

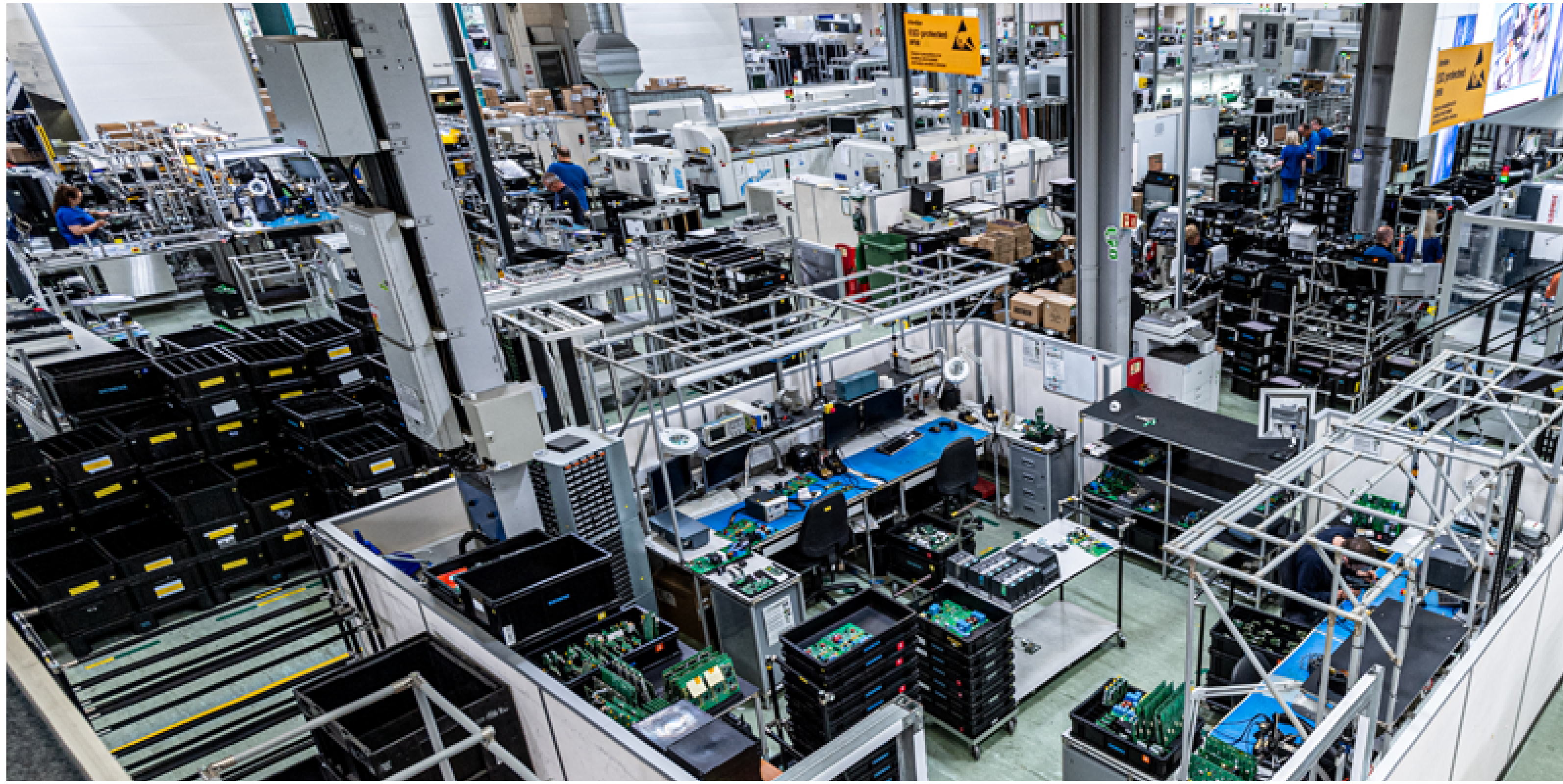
In 2019, Siemens needed to design and manufacture a new product, the G120X, a drive unit that provides efficient regulation of the power fed to an electric motor. These motors can drive a variety of devices, such as pumps or fans, used in the wastewater or heating, ventilation and air conditioning sectors.

If traditional manufacturing methods were used, experience had shown the entire production process would take up to five years. However, the factory site available in Congleton was constrained by location and size, and had an implementation time available of only 12 months.

The use of digital tools allowed concurrent design and manufacture to take place, significantly reducing production timelines. The combination of optimising product designs for automation, using digital twins of complex automations and simulating these systems prior to any physical commissioning has allowed the production line to be installed within twelve months. Together, the design tools simulated the physical, thermal and vibrational parameters of the production and modelled how the entire automation system worked together.

Digitalisation of the factory has more than doubled its production capacity. By using Siemens Congleton as an example, the future UK manufacturing workforce can combine knowledge of digital tools with efficient resource consumption principles to increase manufacturing productivity.

> "If you digitalise an inefficient process, you will create an inefficient digitalised process with lots of waste built in."



Above:
Digital tools and resource consumption principles were used to develop Siemens G120X production line.

Sorting nuclear waste

Mark Robson, Technical Specialist, The Manufacturing Technology Centre (MTC), part of the High Value Manufacturing Catapult; and Mark Wickens, Robotics and Technology Programme Director, Atkins.

The Manufacturing Technology Centre (MTC), in collaboration with Atkins, a member of the SNC-Lavalin Group, has developed an artificial intelligence (AI) driven robotic sorting system which automates the sorting and segregation of nuclear waste.

Current waste processing methods for the decommissioning of nuclear facilities involve manual sorting tasks which are potentially hazardous for the workers involved. The MTC's robotic model uses an AI-based vision system and radiological sensors to identify radioactive waste objects and sort them into appropriate waste streams. This minimises the risk to operators and increases the productivity of the process.

As radioactive waste comes in a variety of different shapes and sizes, the robot's vision model learns to identify individual items. The multi-camera computer vision software gathers multiple views of the waste objects which are fused into a 3D model for input into algorithms. The algorithms inform the robot of the object's shape and location, and combined with sensor data on radioactivity level, drive appropriate waste stream sorting. Every object sorted provides new data points for the vision system, allowing it to use machine learning to become more autonomous with each new item it sorts.

By efficiently sorting nuclear waste into separate streams, items can be directed to the appropriate output. This allows certain, low-risk waste to be recycled instead of placed into storage along with higher risk items, reducing storage costs and environmental impact.

Right:
Artificial intelligence driven robotic sorting system which automates the sorting and segregation of nuclear waste.

Reducing food waste

Jonas Ricknell, Manufacturing Engineer, Mimica.

Mimica is combatting global food waste by developing time- and temperature-sensitive packaging labels which turn from smooth to bumpy once the food is no longer safe to consume.

Food suppliers often provide over-cautious expiry dates as they do not know what conditions customers will store their food in after purchase. This leads to a significant amount of food and drink getting thrown away when it is still safe to consume. Mimica's food spoilage indicator, Bump, uses gel chemistry that liquefies as food spoils, revealing bumps that consumers can detect by touch.

The gel system was designed in partnership with Wrexham Glyndŵr University and mimics food spoilage timelines. For each type of food or drink, the gel is calibrated using data from industry standard spoilage tests so that it decomposes at the same rate as the product inside. When the food has spoiled and the gel liquefies, the plastic bumps give a clear indication to consumers that the food should no longer be consumed.

By partnering with a larger industry organisation, UNITED CAPS, Jonas and his team were able to design an innovative cap for standard drinks bottles which activates the gel system as soon as it is unscrewed by the customer. Working with Intretech UK also enabled Mimica to scale up the gel chemistry system to levels needed for commercial production.

Although their current priority is putting the labels on UK juice caps by the end of 2023, they are also working on a packaging tag format for the meat and fish market.

Above:
Mimica's food spoilage indicator uses a gel that liquefies as food spoils, revealing bumps that consumers can detect by touch.

Replacing plastic with seaweed

Rodrigo García González, CEO, Notpla Limited.

Notpla is a sustainable packaging company combatting plastic pollution by using seaweed and plants as a plastic alternative. Rodrigo identified seaweed as a suitable replacement due to its abundant availability and ability to naturally biodegrade without releasing any microplastics or environmentally harmful waste.

Existing plastic manufacturing systems have been optimised over many years, requiring any proposed replacement to have the ability to be substituted into existing manufacturing lines without the need for significant process changes. Rodrigo has achieved this with the interior coating of cardboard food take-away boxes, and these coatings are now supplied at commercial scale.

The development of their leading product Ooho, edible bubbles that replace plastic packaging for liquids, required the development of unique in-house production machines that are specifically adapted for production scale. The machines fill and form the edible bubbles simultaneously before sealing them ready for use, and have the capacity to manufacture two to three thousand units per day. In comparison, replacements for plastic film are available in small production batches, but require further formulation optimisation if they are to be mass produced by existing manufacturing methods.

Notpla have also started using seaweed fibres to produce seaweed paper. In the long term, using seaweed to replace traditional wood pulp in paper manufacturing is being considered.

> "A plastic item that can be recycled will not necessarily be recycled. An item which degrades naturally is the optimal solution."

Images:
Food packaging developed by Notpla using seaweed instead of plastic.

Image credit: Sam Scales.

Creating bottles from wood pulp

Scott Winston, CEO, Pulpex Ltd.

Pulpex has developed an innovative process to replace glass and plastic bottles with recyclable, single-mould fibre bottles made from sustainably sourced wood pulp that degrades readily in the natural environment.

Having started out as an R&D collaboration between Diageo and Pilot Lite, Pulpex launched in 2020 with the aim of delivering sustainability through renewable packaging. Pulpex quickly built up a team of corporate and sustainability partners to offer a commercially credible replacement for plastic and glass packaging.

The multi-patented process creates bottles from accredited and certified feedstocks using wood fibre pulp from responsibly managed forests. The fibres are used to make a dilute slurry which fills a bottle mould, before the water is extracted to leave the initial shell of the bottle. Once dry and moulded to the desired shape, a chemical coating is applied to the bottles which provides an enhanced barrier to the liquids and powders that they will eventually contain. At the end of use, the bottles can be recycled via existing paper and card waste streams.

Traditional fibre moulding methods were unsuitable for making bottles as they cannot produce a single-piece end result. Significant advances in mechanical engineering, fluid dynamics and additive manufacturing were required to overcome this challenge. Pulpex now creates the bespoke moulds needed to deposit liquid slurries of fibres in such a way as to allow scalable production of single-mould fibre bottles with uniquely customisable sizes, shapes and branding.

Proprietary, specialised coatings are sprayed inside every bottle. The formula varies depending on the intended contents, but currently gives each bottle a 12 to 18-month shelf life by controlling its moisture and oxygen holding properties. As a final production step, the bottles are given an optional exterior coating before being sent to the manufacturer to be filled.

The production of sustainable, wood-pulp bottles reduces global reliance on glass and single-use plastics, ultimately delivering a significantly lower carbon footprint.

"Our ambition is to displace around 2 billion plastic and glass bottles each year by 2028, removing approximately 1 million tonnes of CO_2 emissions per annum."

Images:
Pulpex fibre bottles final product and manufacturing process.

Optimising insect protein production

Matt Simmonds, Managing Director, Entocycle.

Rapid human population growth and growing food supply shortages have led to a need for more sustainable food production. Black soldier fly larvae can provide a source of sustainable, nutritious protein as an alternative to traditionally sourced proteins. However, harvesting the insects at a production scale requires precise control throughout their life cycle. Entocycle has developed technology to allow scale up and automation of insect farming which has previously been unavailable to the sector.

Successful black soldier fly production relies on controlling the number and density of neonates which emerge from the eggs. Neonate numbers have previously been estimated using manual methods, such as by weighing larvae. Entocycle have developed a machine vision neonate counter which can count over 3,000 neonates per second, allowing precise seeding into growth crates and controllable harvesting with lower mortality and larger insects on farms.

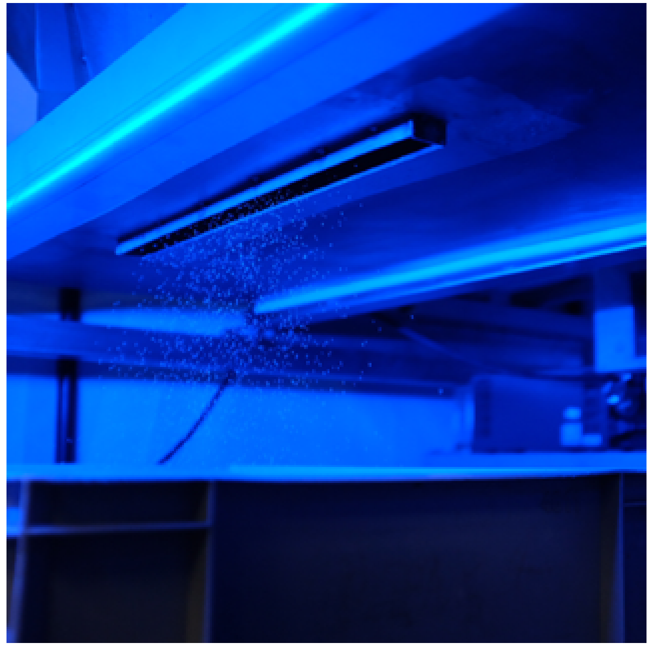
Throughout the breeding process only one percent of the fly larvae are required to reach maturity to breed, leaving the rest to become protein product. Once ready to breed, the efficiency of egg production depends on a number of environmental parameters, such as fly density. To ensure that this density is optimal for egg production, the company has developed an AI-powered fly counter and associated software which can count the flying adults in 3-dimensional space in their fly-rooms.

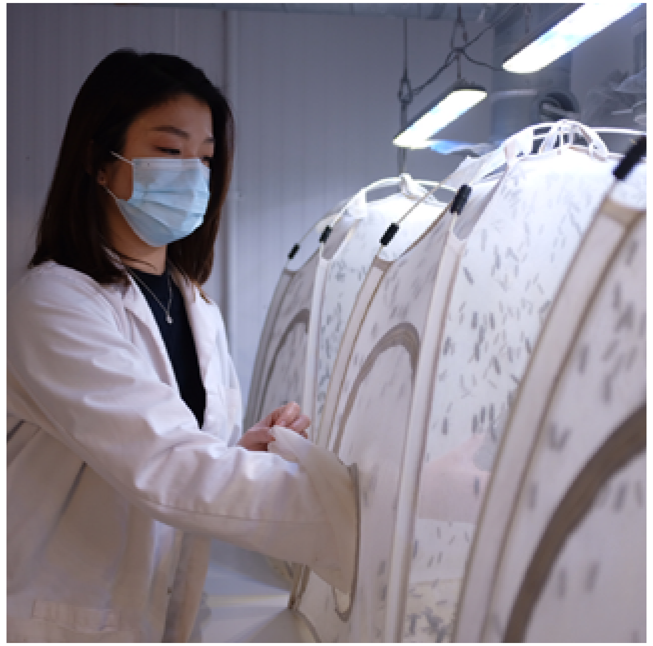
Climate control and ventilation systems ensure that the temperature and environmental conditions remain optimal for each stage of fly and larval growth until harvest. The by-product from the growth crates, frass, is an excellent natural fertiliser for plants.

Matt and his team provide new market entrants with blueprints to entire bespoke insect farms. They also provide existing black soldier fly breeders with their technology to dramatically improve the efficiency of production plants. Their main objective now is to expand the roll-out of their products, commercialise the technology and scale-up the business.

"Funding from the UK science and research investment community allowed us to develop ground breaking technology and patentable intellectual property. This was fundamental in enabling us to attract further venture capital investment for commercialisation."

Images:
Stages of the Entocycle process showing (clockwise from top): black soldier fly eggs; Entomologist checking the fly-rooms; and a Machine Vision Neonate Counter.





Farming salmon sustainably

Ian Laister, Managing Director, Bakkafrost Scotland.

In 2021, Bakkafrost Scotland began a four-year aquaculture innovation project bringing together a variety of different technologies to create the UK's first fully sustainable salmon farm. A central aim was to increase salmon smolt size from 100g to 500g, improving the salmon's survival chances in a marine environment.

Salmon start their life in freshwater and smoltify after about a year, when they begin the process of adapting to salt water. Consequently, traditional salmon rearing processes require salmon to be moved into a marine environment once they have reached smolt stage. This saltwater stage places salmon at an increased risk from viruses, parasites and predators. Bakkafrost Scotland has roughly halved the time needed to be spent in a marine environment using Recirculating Aquaculture System (RAS) technology, simultaneously improving the efficiency of the salmon production process and animal welfare.

RAS technology is an enclosed, indoor, freshwater aquaculture system which creates a bio-secure manufacturing environment for optimised salmon rearing conditions from egg to smolt. A biological filter process removes fish waste and treats the water, enabling 99% of the water to be recirculated and retained in the system. This new facility will allow the salmon to be reared to a larger size in freshwater tanks before they are released into enclosures in the sea.

The end goal is to have the site powered entirely by sustainable energy sources, a 90% reduction in water usage, and a 96% reduction in waste by drying waste matter. The company has already partnered with two local hydropower providers, and the finished facility will be installed with solar panels throughout which will cover the energy requirements for the site.

By bringing together RAS technologies with sustainable energy sources, reusing and recycling materials where possible, this will be the world's first sustainable smolt production facility.

"The technologies have never been used together in this way before. We will change what animal welfare looks like for the salmon rearing sector."

Images:
Examples of Recirculating Aquaculture System (RAS) technology being used to improve production processes and animal welfare of farmed salmon.

Automating vertical farming

David Farquhar, CEO, Intelligent Growth Solutions.

David Farquhar's team have produced a fully automated platform that provides a totally controlled indoor growing environment which can be specifically optimised to grow a wide range of plants. Rather than growing crops commercially, Intelligent Growth Solutions (IGS) supply these platforms to farmers, growers and foresters to provide a hybrid of vertical and traditional farming.

Based on the real-world requirements of their founder, a farmer, IGS have incorporated a suite of technologies from a range of existing industries, such as healthcare and automotive production, to design vertical farming modules called "Growth Towers". The towers are growing machines that come in three heights but otherwise have a consistent design. The priorities throughout the evolution of the system were economic efficiency, scalability, ease of use and maintenance.

Plants are grown in nutrient enriched substrate in trays lit by a proprietary lighting system in a bio-secure environment. Their growth is then monitored, with climate and conditions adjusted throughout the growth cycle to optimise whichever outputs, such as appearance or taste, the grower's customer specifies. The units gather data from sensors and images analysed by massive cloud computing. The results help build knowledge of plant science, enabling continuous improvement and an ever-increasing crop range. Plants, including trees, botanicals, roots and fruits can be grown seed-to-harvest or transferred to the open field or glasshouse environments for further growth.

The machines are deployed across the globe to support growers' requirements and to date have grown over 150 different crops. Each crop has an optimal "growth recipe" depending on the qualities specified for the end product. Once this recipe is identified, any type of plant could be grown, subject to height limitations, including specialised foods, trees, flowers and plant-based pharmaceuticals.

.

"We do not compete with traditional farmers; we are here to supply them with novel infrastructure."

Images:
Example of a climate-controlled vertical farming system provided by Intelligent Growth Solutions.

Extracting collagen from jellyfish

Professor Andrew Mearns Spragg, Founder, Managing Director and CSO, Jellagen.

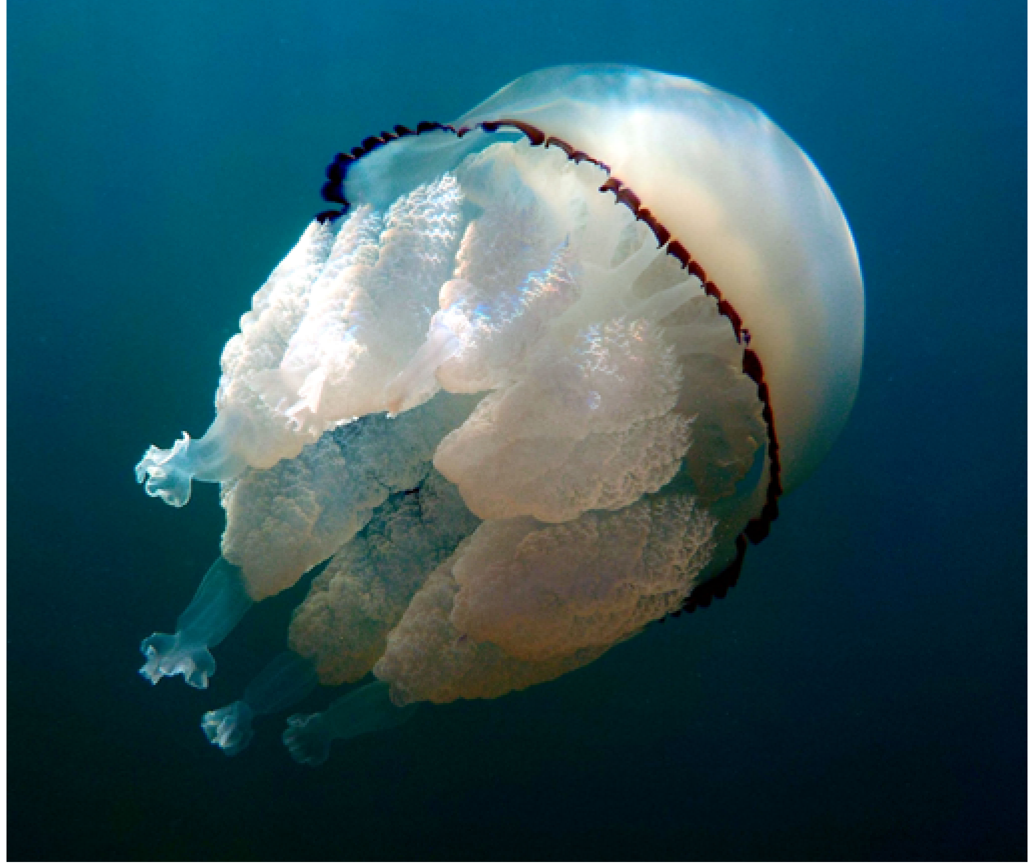
Biotechnology firm Jellagen is replacing traditionally sourced mammalian collagen with collagen sourced from jellyfish. Over the course of five years, Andrew and his team have continuously innovated to develop a scalable collagen extraction process which is both safe and sustainable.

Although collagen has been used in medical applications for many years, it has been typically extracted from mammalian sources, such as pigs, rats, and cows, which poses a risk of human disease transmission and is associated with pro-inflammatory responses. Inspired by his background in marine microbiology and biotechnology, Andrew set up Jellagen with the aim of extracting Collagen Type 0, an ancient form of collagen derived from jellyfish to be used in medical and pharmaceutical markets as a safer alternative.

Collagen Type 0 has the ability to trigger regeneration in tissues as opposed to inflammation. This is achieved by stimulating a lower pro-inflammatory response and a higher anti-inflammatory response than mammalian collagens. Less inflammation allows for a more structured tissue regeneration, offering more potential for this material to promote better healing and improved patient benefits.

There is an enormous overpopulation of jellyfish in UK seas resulting from overfishing of predator species and ocean plastic pollution, with the plastic providing additional surfaces for jellyfish reproduction. Whilst allowing for sustainable jellyfish harvesting, extracting and purifying collagen at scale from a new biological resource still required refinement. Critically, at each stage of the purification process, Andrew was able to develop an optimised proprietary process which does not damage the structure of the collagen and retains the key properties of the protein.

Jellagen partnered with a UK engineering firm that took the company from laboratory scale production to a manufacturing system capable of multi-kilogram level production. They now have the infrastructure to provide large-scale collagen production which can be used globally in medical applications such as tissue engineering, regenerative medicine and cell culture.



"Bringing together academic knowledge with industry experts enabled Jellagen to scale up novel protein purification methods for use in commercial medical applications."

Images:
Jellagen is replacing traditionally sourced mammalian collagen with collagen sourced from jellyfish, which can be used in medical applications such as tissue engineering, regenerative medicine and cell culture.

Producing nucleic acid medicines

Dr Helen Horton, Chief Research Officer, Touchlight.

The global demand for nucleic acid medicines for use in gene therapy, viral vectors and as vaccines is predicted to rise over the next decade. However, traditional production methods using plasmid DNA grown in bacterial cells are time-consuming, costly and difficult to scale. Additionally, the presence of antibiotic resistance genes in the final product is a growing area of concern. Touchlight has developed a cell-free enzymatically produced DNA vector called doggybone DNA (dbDNA) as an alternative to plasmid which is rapid to manufacture and easily scalable to meet future demand.

Starting with a small quantity of plasmid DNA containing the desired sequence, the process uses a high-fidelity DNA polymerase enzyme to generate continuous chains of the required DNA sequence interspaced with sites which are specifically recognised by an enzyme called protelomerase. The protelomerase cuts the chains and then re-joins the desired DNA, now known as doggybone DNA, into discrete linear segments which are resistant to degradation during subsequent purification steps.

dbDNA can be made to good manufacturing practice (GMP) grade which allows it to be utilised in clinical applications such as gene therapy and vaccine manufacturing. The efficiency of the process has enabled Touchlight to build the world's highest-capacity DNA manufacturing facility to make GMP grade DNA.

By working with regulatory authorities who recognised the process could be applied to multiple DNA-based future medicines, a Drug Master File has been accepted by the United States Food and Drug Administration (FDA). This can be used by medicine manufacturers for facilitating more rapid regulatory submissions for therapies made using the process.

The rapidity of the process enables novel interventions for response to diseases such as cancer, where whole genome sequencing can identify patient-specific mutations, and then rapid DNA synthesis can provide personalised cancer vaccine medicine in a realistic timeframe. In the future, rapid DNA production will have a positive impact on wider society as it enables a quick vaccine response to a pandemic.

"Academic collaborations have been pivotal in evidencing the applications of our doggybone DNA technology."

Images:
Touchlight has developed a cell-free enzymatically produced DNA vector as an alternative to plasmid which is rapid to manufacture and easily scalable to meet future demand.

Manufacturing oligonucleotide medicines

Dr Barrie Cassey, Medicines Manufacturing Technology Lead, CPI.

Dr Barrie Cassey is the Medicines Manufacturing Technology Lead at CPI, a technology innovation catalyst which is part of the High Value Manufacturing Catapult. CPI accelerates the development, scale-up and commercialisation of advanced technology and sustainable manufacturing solutions by working with industry, academia, government, entrepreneurs, and the investment community.

Therapeutic oligonucleotides, a relatively new class of medicines made from short strands of DNA or RNA, demonstrate significant potential to operate against ‘undruggable’ disease targets where, to date, other medicines cannot. Oligonucleotide medicines work by interfering with gene expression and have shown success in the treatment of rare diseases. As such, researchers are now exploring the potential of these therapeutics to treat chronic diseases that affect much larger patient populations, such as heart disease and cancer.

The current manufacturing process, known as solid phase synthesis, is expensive and inefficient. The method assembles the oligonucleotide by anchoring one end to a solid support packed in a column, adds monomers sequentially to extend the chain, and then flushes away unused monomers before preparing for the next round of synthesis. The product is then cleaved from the support and purified. This method was originally developed for laboratory use and uses solvents which are environmentally harmful and in limited supply globally. Consequentially, the current manufacturing process is not scalable and unable to provide the quantities of oligonucleotides that will be required to meet the predicted global demand.

One of the Government’s Grand Challenges for the life sciences was to identify a scalable and more cost-effective medicines manufacturing process for therapeutic oligonucleotides. Working alongside AstraZeneca, Novartis, Alnylam and UK Research and Innovation, CPI has adapted a novel process developed by Exactmer, a spin-out company from Imperial College London, to create a scalable solution phase manufacturing method.

In the modified process, the oligonucleotide polymer chains are extended on a support in solution, and the growing chains filtered from the unused monomers through nanofiltration before the next monomer addition step. The product is then split from the support prior to further purification. The modified process requires less solvent, and, since it is not constrained by column size, allows manufacture at scale.

“The knowledge input from our pharma partners is as important as their financial support. At team meetings, whenever I have a question on the manufacturing process, there will be somebody in the room who has an answer.”

Images:
Development of a modified process to tackle the challenge of producing therapeutic oligonucleotides at scale.

Building nuclear power plants

Matthew Blake, Chief Engineer, Rolls-Royce Small Modular Reactors.

More clean electricity will be needed in order to achieve the UK's 2050 net zero goal. Towards the end of 2015, Rolls-Royce launched their small modular nuclear reactors (SMRs) project with the aim of commoditising a nuclear power station that can provide an affordable, low carbon power source that generates electricity using a small modular reactor. The result is a scalable, factory-built nuclear power plant providing clean energy with the potential to be deployed on a global scale.

Matt Blake, Chief Engineer at Rolls-Royce SMR based in Derby, was tasked with engineering the construction of the small modular reactors. Traditional nuclear power stations are expensive to build and difficult to deliver to schedule. Consequently, the key priorities were to minimise cost and to ensure the SMR production was deliverable, scalable and investable.

Matt and his team devised an innovative construction process by developing a 'kit of parts' which make up an SMR plant. Each kit contains approximately 35 million parts, each of which is manufactured in factories and made into standardised modules before being transported by road to the site and assembled to form the SMR plant. By creating a factory flowline production of standardised parts, Rolls-Royce SMR has significantly reduced the amount of on-site construction. The simplicity and repeatability of the production process allows for reactors to be installed with a greater level of cost certainty and operational efficiency than traditional nuclear power plants.

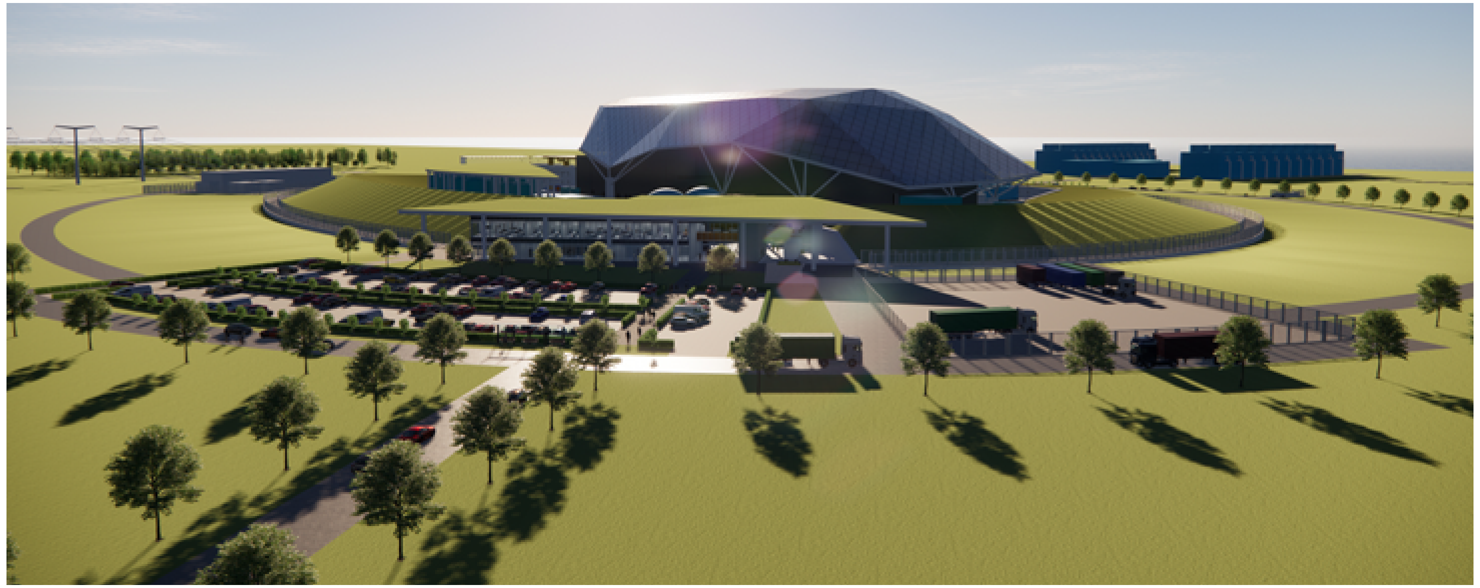
When designing the modules, Matt had to consider their weight and size for road transportation, their size for factory storage and how easily they can be deployed on site. 3D digital modelling was used to determine how the reactor should be assembled, including where to place the machinery, the sequence of module installation and how construction workers would move around the site during assembly.

Further innovations exist outside of the power plant's modular design. Rather than manually disposing of the soil excavated from site production, it is instead used to encircle the power plant and provide protection from flooding. Additionally, the construction site is covered by a steel roof which further reduces the impact of weather constraints. Steel, rather than concrete, is also used as the material in the containment of the reactor.

Rolls-Royce SMR aim to have units operational in the UK by the early 2030s. The scalability, repeatability and adaptability of the SMR design has led to increased global interest as countries look to reduce their carbon output and meet climate targets.

"Rolls-Royce SMR were able to achieve the design by pooling together existing specialist knowledge from prior experience in automotive, jet engine and submarine production."

Images:
The Rolls-Royce SMR team have developed an innovative construction process made up of a 'kit of parts' resulting in a scalable, factory-built nuclear power plant providing clean energy.



The Royal Society

The Royal Society is a self-governing Fellowship of many of the world's most distinguished scientists drawn from all areas of science, engineering, and medicine. The Society's fundamental purpose, reflected in its founding Charters of the 1660s, is to recognise, promote, and support excellence in science and to encourage the development and use of science for the benefit of humanity.

The Society's strategic priorities are:

- The Fellowship, Foreign Membership and beyond
- Influencing
- Research system and culture
- Science and society
- Corporate and governance

For further information

The Royal Society
6 – 9 Carlton House Terrace
London SW1Y 5AG

T +44 20 7451 2500
W royalsociety.org

Founded in 1660, the Royal Society is the independent scientific academy of the UK, dedicated to promoting excellence in science

Registered Charity No 207043
Issued: March 2023 DES8270_4