CATALYST

Edition 34

In this issue:

Welcome

Welcome to another edition of Catalyst - aimed at young people, we're proud to bring you cutting edge research that sparks debate.

This edition features articles on the role worms in Space can play in improving health on Earth, how scientists from more than 100 countries are taking physics to a new frontier, and the future of wearable technology. We hope you enjoy this edition. If you have any ideas for future topics you'd like to see covered, please get in touch via our email: **catalyst@stem.org.uk**

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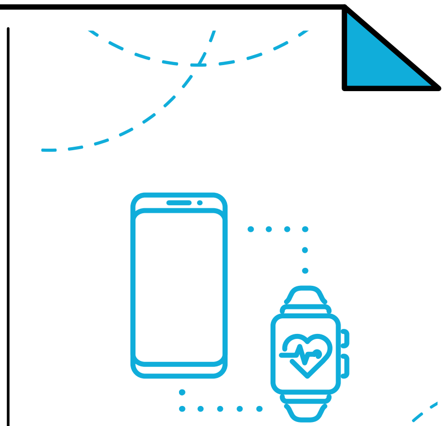
Contents



Career journey with
Hannah Sargeant

**Research Student,
The Open University.**

> "Studying for a PhD means I get to research something that has never been done before!"

Q Tell us a bit about yourself and what you do.

A I am a PhD researcher working on an instrument called ProSPA which will be heading to the lunar south pole in a few years time. The instrument is part of a package of European Space Agency (ESA) instruments on board a Russian lander called Luna-27. We have never landed a mission at the lunar south pole before, and because a lot of the areas are permanently in shadow it means they get extremely cold and therefore have very different characteristics. The ProSPA instrument will help us to understand these regions of the Moon. I spend a lot of my time in the lab building and testing to make sure ProSPA will be able to perform the experiments we plan to do.

Q What inspired you to work as a space scientist?

A I've always had a passion for learning about space and it was my dream to work as a space scientist. I was lucky enough to visit the Kennedy Space Centre when I was younger and I got to see a live Space Shuttle launch! Ever since I have wanted to work on space missions and perhaps one day work at mission control. To get to where I am today I studied science and maths in school and then at college. I then studied physics at university. Because I've always enjoyed science and working with young people, I then became a science teacher, which I loved. After a couple of years I decided to go back to university to chase my dream of working in the space industry.

Q What are you working on at the moment?

A Currently, I am looking at ways to create water from Moon rocks. If we want astronauts to be able to live on the Moon for long missions we have to find water because it's just too expensive to bring all the supplies with us. However, the Moon is thought to be bone dry in most areas so we would have to find a way to create water from the rocks themselves. I am testing the best ways to create water from Moon rocks using chemical reactions, this is a type of In-Situ Resource Utilisation, or ISRU. We are hoping to perform the first ever ISRU experiment on the lunar surface with the ProSPA instrument.

There are many routes into the space industry; biology, chemistry, engineering, geology and even geography.

Q How will you test if your experiments work?

A I am currently building a prototype of the ProSPA instrument that we will use on the Moon and I am using it to heat certain minerals with hydrogen to produce water. The machine was really fun but challenging to build and it taught me that science is not all lab coats and test tubes, there's a lot of hitting things with spanners and crossing your fingers when nothing seems to be working! So far I have proven that we can make water from the mineral ilmenite which is commonly found on the Moon. The next step will be to test my experiments on lunar meteorites and real samples collected from the Apollo missions. I will also try and find the best technique to use to get the most amount of water which includes testing different temperatures for the reaction, different pressure of hydrogen, and different types of mineral. I also get to use lots of sample analysis machines such as an x-ray diffraction machine which looks at the mineral structure after the reaction. Such machines allow me to look at the reacted minerals and look for evidence of the reaction and help me to determine how efficient the reaction is.

Q What's the best thing about your job?

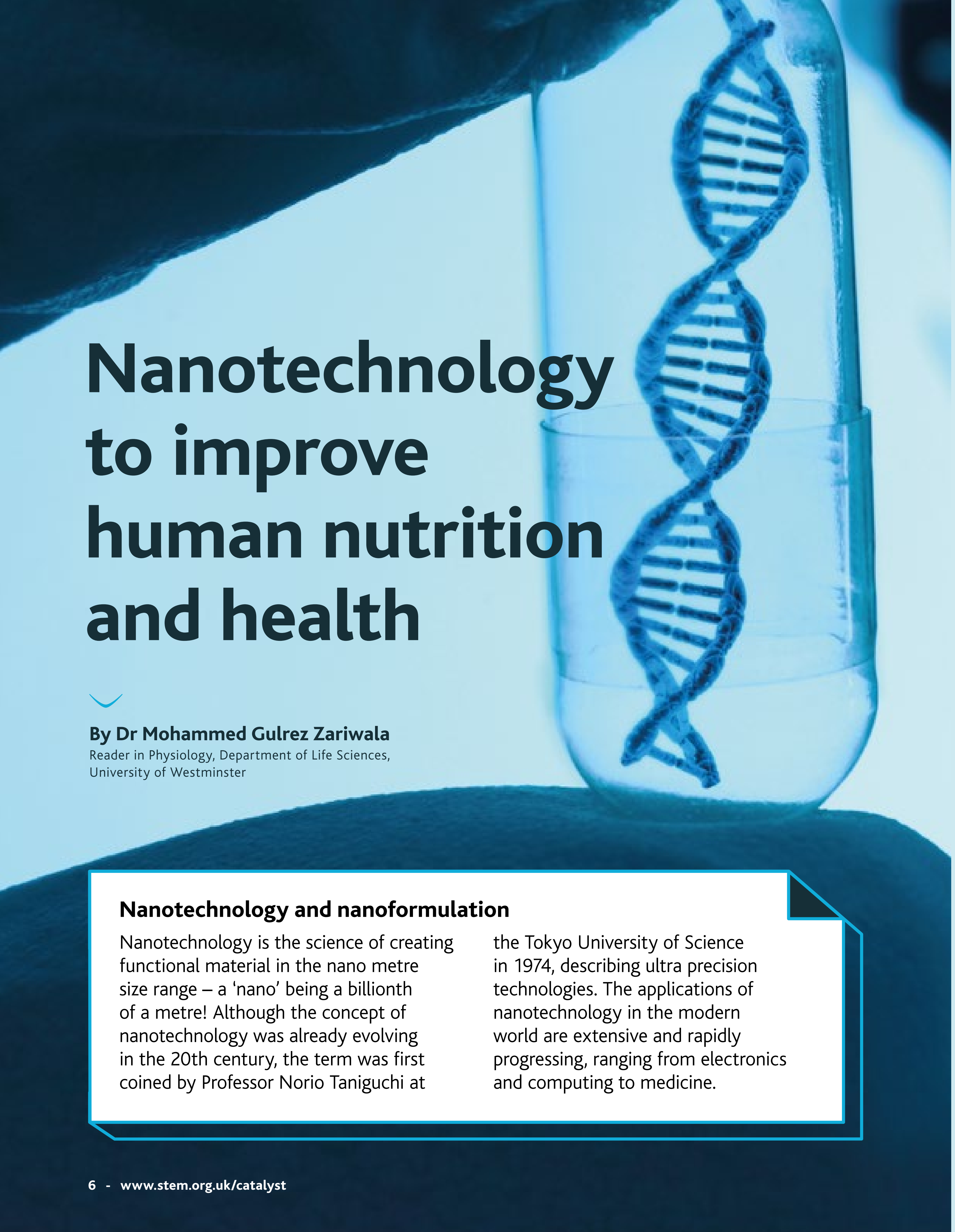
A One of the best parts of my job is that I get to travel to exciting places, either to conferences or to learn new skills. Conferences are great places to share work with other scientists doing similar things, and I have been able to attend conferences in Germany, France and the Netherlands. I have also been to training events in Belgium and I spent my summer at NASA in America where I learnt lots about lunar geology and helped with future NASA missions! My favourite part about being a lunar scientist is that every day is different. I am always learning something new and meeting exciting people. Also, by studying for a PhD it means I get to research something that has never been done before!

Q What qualifications did you need to get to where you are now?

A Along with my physics degree I did a Master's degree in Space Exploration Systems which taught me about space science and geology, and engineering. Now I am doing my PhD, which is part of a Moon mission, and I am using lots of skills including lunar geology, chemistry, physics and engineering.

Q What advice would you give to someone wanting a career in space science?

A If you would like to have a career in space or planetary science then of course studying science is very important. If you have a real passion for geology and planetary science then geography can also be very useful. What I have learnt is that there are many routes into the space industry. For example, engineers can go on to build and test rockets, chemists can work on sample analysis of comets, biologists can study what conditions would be possible for life on other planets, and geologists can help us understand how the planets formed. Even those who aren't huge fans of science can go into space law, as we explore further into space we need to have better rules and laws that make sure we maintain peace in space!



Nanotechnology to improve human nutrition and health

By Dr Mohammed Gulrez Zariwala
Reader in Physiology, Department of Life Sciences, University of Westminster

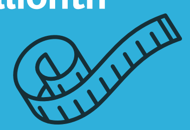
Nanotechnology and nanoformulation

Nanotechnology is the science of creating functional material in the nano metre size range – a 'nano' being a billionth of a metre! Although the concept of nanotechnology was already evolving in the 20th century, the term was first coined by Professor Norio Taniguchi at the Tokyo University of Science in 1974, describing ultra precision technologies. The applications of nanotechnology in the modern world are extensive and rapidly progressing, ranging from electronics and computing to medicine.

Today, for instance, we see nanotechnology use in our clothing, mobile phones and cosmetics. Formulation science is the methodology of developing and manufacturing cosmetics, pharmaceuticals and chemicals using specific techniques, blends and proportions to create 'formulations'. The advent of nanotechnology has led to its use in creating 'nanoformulations', in particular for medicinal drugs in the pharmaceutical industry. These drug nanoformulations have the advantage of improving the properties of conventional drugs by making them more potent and able to target specific sites in the body.

As nanoformulations present an appealing means of preserving beneficial characteristics of a substance while enhancing its absorption and potency they hold great potential for human nutrition and health. However, although the benefits of nanotechnology and nanoformulations are undeniable, there have been concerns about their safety and impact upon the wider ecosystem. Many nanoformulations use synthetic chemicals and therefore their use in food and nutrition application can be controversial. These concerns can be allayed by using naturally occurring components already used in food ('biomaterials') to develop nanoformulations for human nutrition.

A 'nano' is a billionth of a metre!



Natural 'bioactives' and human nutrition

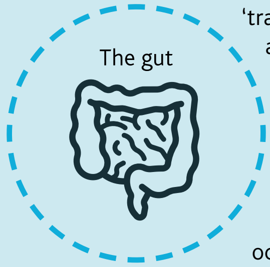
Naturally occurring substances such as botanicals and antioxidants ('bioactives') have several beneficial health-promoting effects. For instance, antioxidant 'actives' found in natural foods such as fruits and vegetables can protect against oxidative stress and play a role in countering diseases. Resveratrol from grapes and lycopene from tomatoes are antioxidants known to have such beneficial effects. Oxidative stress occurs when unstable reactive molecules termed 'free radicals' scavenge the body and attack and damage cells, proteins and DNA. These can normally be countered by the body's antioxidant defences but in excess they can overcome and play a role in development of disease states such as Alzheimer's, type 2 diabetes and cancer. We can obtain antioxidants from dietary sources, but may not consume these foods in sufficient quantities to provide us with the required amounts of antioxidants to prove effective enough.

Extracting these antioxidant compounds from foods and manufacturing them into pills and other forms to be taken as 'nutraceutical' supplements provides an innovative way of utilising them at the right dose. However, extraction from the natural state causes many antioxidants to become unstable and less active and this can lead to low absorption and activity in the body.

Nanotechnology is used in:

Nanoformulation of bioactives to maximise their benefit

Nanoformulation can overcome these limitations and provides an efficient way to package these antioxidant extracts and deliver them into the human body for maximum effectiveness. Unlike drug nanoformulations, nanoformulations for food bioactives would require use of food-based ingredients to make them more suited for daily consumption. Food-derived natural origin material such as proteins and polysaccharides are relatively inexpensive and already used widely in the food industry, presenting an attractive resource to develop bioactive nanoformulations. For instance, we and others have used natural source ingredients, such as whey protein from milk and chitosan from fungus, to develop nanoformulations of several antioxidants in our lab. This requires a combination of material science, cell biology and pharmaceutical techniques. A 'bottom-up' approach is used to assemble and combine ingredients to craft intricate structures in which the bioactive substance is packaged in a nano-size shell. This allows protection of 'trapped' bioactives, keeping them stable and also ensuring high absorption in the body as the nano size leads to increased entry into the body via gut cells. During development absorption, action and any undesired effects are first tested in human cells grown in the lab to mimic what occurs in the body. Once we know the nanoformulation is safe, studies can be conducted in humans to further confirm its absorption and activity. As an example, curcumin, a substance present in the curry spice turmeric is one of the most researched antioxidants and has been scientifically shown to be beneficial in a number of conditions ranging from pain and inflammation to healing wounds. Curcumin is poorly absorbed in humans but developing nanoformulations of curcumin leads to much improved absorption and beneficial effects.



Despite these advances, nanoformulation of bioactives is a new field and has not developed to its full potential so far. As yet, very few nanoformulated bioactives are available in the market but the current rapid progress suggests that we may not be very far off from being able to access these in the supermarket. Advancements in the science of nanoformulating bioactives as food supplements may therefore in future provide a novel drug-free approach to counter the progress of modern-day diseases.

Future circular collider

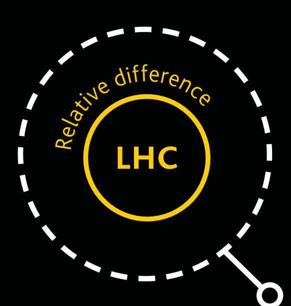
By Professor Carsten P. Welsch

Communications Coordinator for the European Circular Energy-Frontier Collider (EuroCirCol) project

Scientists from more than 100 countries design the world's largest collider - taking physics to a new frontier.

Setting a big goal provides an exciting challenge, and in science – as well as in technology – it can increase the possibilities of discovery too. For example, the race to put a man on the Moon encouraged innovation in computing, aeronautics and fuels.

Seven times the power of the LHC.



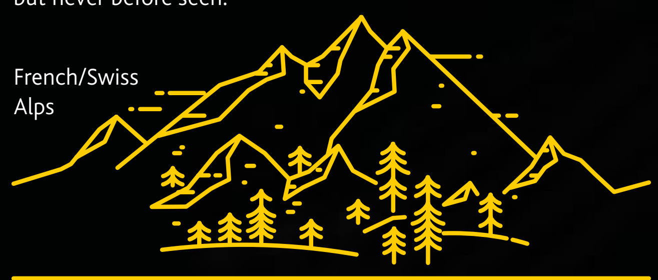
Four times bigger than the LHC.

Now work has begun on designing the largest particle accelerator the world has ever known. By achieving energy levels even closer to those of the Big Bang, the new accelerator hopes to find new particles and offer a deeper understanding of the rules that govern the universe.

Back to where it began

At almost 17 miles long, the Large Hadron Collider (LHC) buried under the French/Swiss Alps is currently the world's largest particle accelerator. Designing and building the LHC, which was first started up just over ten years ago, was an aspirational project. It set out to confirm what we knew about the structure of hadron particles, such as protons, and smash them together to discover new particles. The most exciting discovery for physicists was the Higgs boson, a fundamental particle predicted to exist but never before seen.

French/Swiss Alps



The LHC was successful in reaching energy levels approaching those of the Big Bang, at the start of the universe. It has given insights into how particles first gained mass and then became the matter that makes the things we can see around us.

For wider society, building and running the world's largest particle accelerator also had other benefits. Scientists needed a better way to communicate and so they developed the technologies that formed the basis of the world wide web, the internet, to allow the sharing of big data such as video. The beams created at the LHC have enabled new types of cancer treatment, such as proton beam therapy. Other discoveries include novel semiconducting materials, which are used in computing and offer new ways to preserve and treat food and water.

International efforts

To continue to expand our scientific discovery even greater energy levels are needed, so now scientists have begun to design a Future Circular Collider (FCC). It will have seven times the power and be four times bigger than the LHC, and will reach unprecedented energy levels. To achieve this goal, the project needs the cooperation of more than 100 countries from across the world and the input of thousands of scientists.

The new 100 tera-electron-volt (TeV) accelerator will use high-energy electric fields to speed up the particles in a 62-mile tunnel. The particles will need to be constrained to form beams that will bend in a circular trajectory.

The new circular collider will use high-energy electric fields to speed up the particles in a 62-mile tunnel.

This will be achieved through the use of superconducting magnets, cooled to temperatures below those of outer space using large-scale cryogenic systems. Current magnetic fields in the LHC reach 8 Tesla; the new magnets will reach 16 Tesla.

The knowledge of how to achieve these magnetic fields and build these high-field magnets does not yet exist, so this work is part of the FCC programme. A number of key enabling technologies – from accelerator structures to efficient cryogenics – are needed to ensure a reliable and efficient operation of this large-scale research infrastructure.

Proving (or disproving) the rules of the universe

The Standard Model of Physics is used to describe our current understanding of fundamental building blocks of the universe and how they interact.

The FCC will take physics to a new frontier, revealing information about particles predicted by our existing Standard Model of Physics, but not yet seen – such as candidate particles for dark matter. There is also the possibility that the FCC programme will disprove parts of the Standard Model by showing particles which do not have the characteristics we expect.

Scientists hope it will also resolve some of the gaps in our understanding. For example, why is there so little antimatter in the universe when it should be in equal quantities to matter?

Just being part of the design study is inspirational and having a big goal helps not only to focus efforts, but is also inspirational for all of us working in this field.

The FCC collaboration delivered a report in January 2019 that outlines the conceptual design for this exciting new circular collider. What to build, how to build it and the main experiments are still to be agreed upon, and this will inform the discussion within the annual FCC conference.

If you would like to build your own accelerator The Cockcroft Institute has developed an augmented reality app that allows you to construct your own virtual accelerator and see how it works using a smartphone app and cubes of printed paper.

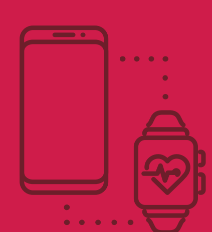
For more information about the augmented reality app visit: acceleratar.uk

For more information about the FCC visit: t.co/uL5erroJUi

The future of wearable electronics

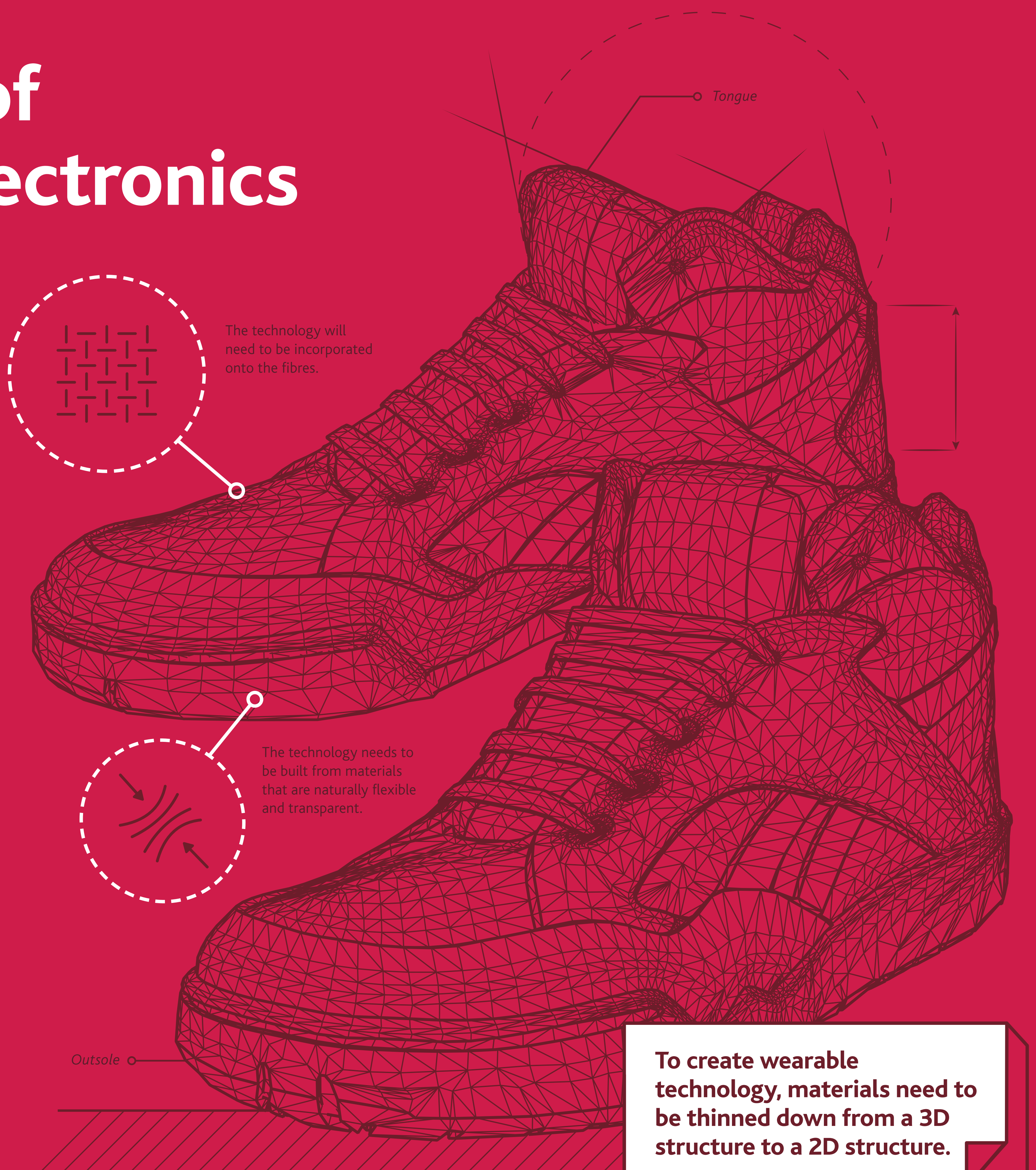
By Nicola J. Townsend
Research Associate, Department of Engineering, Durham University

In our modern-day lives we are exposed to a wide range of technological advancements that were not as developed even 20 years ago. Consider something like a mobile phone: almost everyone has one and uses them not just for phone calls and text messages, but as our connection to the whole world through their internet connection.



Mobile phones are our personal music players, our cameras and our navigation devices. Mobile phones have been recently paired up with watches, so the 'chore' of taking your phone out of your pocket is now a thing of the past. What is the next step for our technological advancements? Wouldn't it be great if we no longer had to remember to pick up our phones when we go out, but instead if they were embedded into our clothes without dangling bulky components and tangled wires reducing the textile flexibility?

To make these dreams a reality, we need to carry out scientific research to improve the electronics available to us. Currently, most of the components in our electronic devices rely on brittle materials such as silicon and gallium arsenide, but these devices are rigid and generally opaque. But, what if we could replace these components with ones built from materials that are naturally flexible and transparent? This is where the exciting world of novel two-dimensional materials comes in.



To create wearable technology, materials need to be thinned down from a 3D structure to a 2D structure.

In 2004, graphene, which is a one-atom-thick layer of carbon, was isolated from graphite (a layered carbon material that you have in your pencil tips) and was shown to have extraordinary properties including transparency, flexibility and a high electrical conductivity, exceeding even that of copper. These properties give graphene the potential to be used as a replacement for silicon for the purposes of wearable electronics, but graphene lacks a crucial property. Our technology is built on components, which act as electronic switches, which can either switch on or off depending on an external stimulus. Graphene cannot behave as a switch, which limits its usefulness in these new technologies.

However, not all is lost in the pursuit of wearable electronics. Graphene has, nonetheless, played a vital role in the advancement of the field, by inspiring scientists to seek alternative solutions. There is a wide range of other materials that have a layered structure similar to that of graphene and can also be thinned to a single layer, though this time they are three atoms thick due to their chemical composition. However, whilst they are also transparent and flexible, they do show the required switching behaviour that is vital for our technology and have the potential to be a replacement for silicon in our new wearable electronics.

This almost sounds too good to be true, but the changes are going to be very slow. When the materials are thinned down from a 3D structure (which we term the 'bulk') to a 2D structure, there are many challenges which become dominant and need to be controlled and mitigated. Think about if you bake two cakes with one chocolate chip in each, and then want to trace a line directly through each chocolate chip. If one cake is much thinner than the other whilst having the same diameter, the probability of the path crossing the chocolate chip is much greater in the thinner cake than the thicker one. A similar concept applies in these materials, but instead of being chocolate chips, it can be missing atoms or a different atom bonded to the surface, which we collectively call defects, and can affect the performance of the device. In a bulk device, the presence of defects is mitigated by the large volume of the structure. In single layer materials, these defects will be very prominent and affect the reproducibility of our devices. In order to obtain reliable devices which can be manufactured in very large numbers, we need to fully understand the nature of defects so that we can either control them, eliminate them or even utilise them for our benefit.

Once we learn how to control the defects in thin materials, the next step will be to incorporate them onto fibres that can be woven together to create a fabric. This will reduce the need for pesky wires going through your clothing as the wires and the fabric will be one and the same.

The difficulty in incorporating materials on fibres arises from the rough surface of the fibres on an atomic scale, which can cause the materials to develop defects. Again, this is another avenue for research that is currently underway.

Whilst it seems like the dream of a phone embedded in your jumper is a long way off, there is hope through a wide range of research encompassing many different disciplines to make truly wearable technology a reality in the near future.

C. elegans have many similarities to humans. They have muscles, a gut, nerves and a circulatory system.

Worms in Space for Health on Earth

By Dr Colleen S. Deane
Research Fellow, University of Exeter

Spaceflight is an extreme environment, which causes many negative health adaptations to the body including the loss of muscle and bone mass. The loss of muscle mass is so extreme that it equates to ageing 40 years in a single year of spaceflight. In order to combat the negative adaptations of muscle during spaceflight, astronauts exercise daily on the International Space Station (ISS), performing endurance (i.e. cycling and running) and resistance (weight-training type) exercise.

However, after a six-month stay on the ISS astronauts display visible losses in muscle function requiring weeks of rehabilitation to regain their muscle mass. This means that the current exercise interventions are not effective, and we need to understand the underlying changes causing the loss of muscle mass during spaceflight in order to generate more effective interventions.

Our Molecular Muscle Experiment (MME) involved sending microscopic worms (C. elegans) to the ISS in order to:

I. try and identify the exact molecules causing muscle problems during spaceflight

II. test the effectiveness of new therapies for preventing the loss of muscle during spaceflight

Why are worms used for research?

We use the microscopic C. elegans worms because they are small, allowing scientists to keep millions of them at a time and they are easy and cheap to maintain. Surprisingly, C. elegans also display many similarities to humans. For example, C. elegans have muscles, a gut, nerves and a circulatory system, and in order to move C. elegans convert food into energy, just like humans. Whole genome sequencing revealed that C. elegans have ~19,000 genes, humans have ~25,000 genes and up to 80% of the genes in C. elegans are similar to human genes. So, C. elegans are an ideal organism for studying the impacts of interventions (e.g. spaceflight) on muscle health.

A single year of spaceflight can cause extreme muscle mass loss, equivalent to ageing 40 years!

What about worms in space?

Very early research showed that C. elegans are able to grow and reproduce in space, and much like humans, display no major obvious longer-term health problems. Interestingly, worms and humans display similar molecular changes related to muscle sensing and energy use in response to spaceflight, which if occurred on Earth, would lead to diabetes and muscular dystrophy in both humans and worms. So, understanding how and why spaceflight causes these changes in worms might tell us why the same changes occur in astronauts and may help us improve treatments for diabetes and muscular dystrophy.

So, our theories for the MME are:

I. cell sensing of energy use causes muscle decline in space (i.e. genes associated with diabetes progression)

II. cell sensing of mechanical loads causes muscle decline in space (i.e. genes associated with muscle strength)

Pre, during and post-flight operations

Doing scientific experiments in space is different to doing them on Earth in a laboratory because the equipment is different, there is limited space on the ISS and the scientists do not usually conduct the experiments themselves. This means that lots of preparation is done ahead of the launch to make sure that the necessary equipment has been developed and trialled for the real experiment.

Ahead of the launch, the first step was to get the C. elegans ready for loading onto the rocket, and like humans, C. elegans require food, water and oxygen. The C. elegans were placed in specially designed bags that contained the nutrients and allowed gas exchange (i.e. oxygen and carbon dioxide), which the worms need to survive during spaceflight. These worm-containing bags were housed in special cassettes (image 1) that ensure the worms do not get too hot or too cold, as temperature determines how long the worms live for!

Image 1. Samples for the MME inside the spaceflight hardware.

Once the worms were packed up, they were handed over to a cold stowage team ready for launch. The C. elegans were launched to the International Space Station on board the Space X Falcon 9 CRS-16 Dragon capsule on 5 December 2018. After the Dragon capsule had docked with the ISS, the worm-containing cassettes were placed inside the Kubik incubator at 20°C (image 2), and remained there for five days. After this incubation period, the worms were frozen at -80°C, inside the Minus Eighty-Degree Laboratory Freezer for ISS (MELFI). The worms were returned to Earth on board the Dragon capsule by splash landing into the Pacific Ocean on 13 January 2019 and were returned to the University of Nottingham shortly after. Post-flight analysis of the samples will commence later this year, and we should begin to understand how cell-sensing of energy use and mechanical loading contribute to spaceflight-induced muscle loss.

Image 2. Astronaut Alexander Gerst.

Explosive-eating GM plants are having a blast!

By Liz Rylott
Plant Biotechnologist, University of York

TNT contamination is still present in soil dating from WWI and WWII.

I think I have my dream job… plants are fantastic, science is cool, our precious environment needs help and my job involves all three. Here, at the Centre for Novel Agricultural Products (CNAP), in the Department of Biology at the University of York, I use genetic modification (GM)-based technologies to develop plants that clean up environmental pollutants. But, unbelievably, it's even more exciting than that: our plants clean up explosives!

It's not a well-known fact but explosives are environmental pollutants. A major ammunitions component, TNT (2,4,6-trinitrotoluene), is one of the biggest offenders; its lesser-known cousin RDX (hexahydro-1,3,5-trinitro-s-triazine), is its partner in crime. Explosives pollution occurs in the environment through the manufacture of TNT and RDX; their use in munitions where incomplete detonation delivers particles of these compounds into the environment; and during decommissioning, bombs have 'use-by' dates. Who knew? The extent of the pollution is staggering – in the US alone, over 10 million hectares of military land is contaminated with munitions components. The clean-up costs are eye-watering: $16 – $165 billion, and the toxic and carcinogenic potential chilling; in WWI and WWII, many women working in the munitions factories were hidden casualties, losing their lives to liver diseases caused by TNT.

But how to clean up this mess? The sheer scale of the pollution means that we can't just dig it up and incinerate it (a method that can be used on small-scale contamination). Often, the exact location and degree of contamination is not fully known, and may contain unexploded bombs, so it's not a place to wander about on! And we can't just leave it; these explosives are so resistant to degradation in the soil that serious TNT contamination is still present in Europe dating from WWI and WWII.

In the US alone, over 10 million hectares of military land is contaminated by explosives.

We need something that can delve into the soil, extract and detoxify the pollution, without causing further environmental damage, which ideally requires minimal maintenance and is cost-effective on a large scale. So, to find something that can detoxify these compounds we examined bacteria from explosives-contaminated soil. Explosives are stuffed full of nitrogen, a limiting element for bacteria growing in many range soils and thus there has been a high selective pressure for these bacteria to evolve the ability to 'eat' explosives. Compared to plants, bacteria have incredibly fast life cycles enabling them to evolve much more quickly. By feeding cultures of bacteria from these contaminated range soils with explosives as their only nitrogen food source, we were able to isolate, and study, explosive-eating bacteria.

After a few more years in the lab, we had worked out which bacterial genes were responsible, named them (NR, XplA and XplB), and introduced these genes into some plants. We used a model plant species called Arabidopsis thaliana (common name Arabidopsis). It's a relative of the oil seed rape plant (those yellow fields that you can see in the UK), but smaller, quick growing and easy to genetically modify.

The day we tested our first big experiment in the lab and found out that our GM plants could degrade the explosives was a real eureka moment!

We used some new technology called transcriptomics (the study of the sum total of all the messenger RNA molecules expressed from the genes of an organism) to see which of the thousands of genes in Arabidopsis could also be involved in detoxifying explosives. Studying these genes helped us understand a lot more about how plants respond to the explosives, and what we could tweak to make an improved explosives-detoxifying plant.

But you can't drive a tank over lettuce…and Arabidopsis is a lot like a lettuce: green and crispy. So, we chose switchgrass, Panicum virgatum (well actually, we chose other species first, but we couldn't get those to work; not everything goes to plan in science). A perennial species native to the training ranges, switchgrass has adapted to thrive in the harsh conditions there, with roots that penetrate deeply into the soil to hoover up the explosives, and, an important consideration for the military, the ability to withstand being repeatedly driven over by a tank!

After some important paperwork to assess and risk manage any environmental consequences of testing our plants outside of the controlled conditions of the laboratory, the US military let us trial our grasses on their training range. We are now just coming to the end of a three-year field trial. There is a mountain of plant material, soil and water samples to analyse, and lots of data to evaluate. But at the end of this – now nearly 20 year-long – scientific odyssey, we will finally get to see if our GM technology could actually be used to clean up explosives pollution. Will we have our bingo moment?

Notes:

Collaborators on this project include Prof Neil Bruce, CNAP; Prof Stuart Strand, University of Washington; Timothy Cary, US Army Engineer Research and Development Center, Cold Regions Research and Engineering Laboratory.

Beeswax and the Weak Force

By Jeremy Britton
Adjunct Professor in Civil Engineering,
Portland State University

I'm visiting Aaron Webster at the Lewis and Clark Interpretive Center in Washington State. In 2003, Aaron found a round of beeswax on one of the rock-mound jetties jutting into the Pacific Ocean. Researchers think a Spanish galleon carrying Chinese porcelain, liquid mercury and beeswax crashed about 65 kilometres south of the jetty in the 1690s. The wreck is yet to be found, but several pieces of beeswax have been discovered.

My objective is to understand the weak force, one of the four fundamental forces of nature. To help myself learn, I'm doing a science project. The weak force turns carbon into nitrogen in a process called beta decay. Radiocarbon dating uses this process to estimate when something died. My mission is to find old organic matter and date it. I would have used a twig, instead, Aaron has offered to cut a wedge from his beeswax.

Aaron leans in and works a knife back and forth to penetrate the stiff wax. We lament disfiguring the artifact, but it's for a good cause. I put the sample in a zipper bag and send it to a lab. The result is due in one month.

Living plants and animals contain a small amount of carbon-14: atoms with six protons and eight neutrons in their nuclei. When a plant or animal dies, the carbon-14, which is radioactive, decays at a known rate. You can estimate when something died by measuring how much carbon-14 remains compared to the amounts of stable carbon (-12 and -13).

What's happening inside a carbon-14 atom when it decays? One of its neutrons transforms into a proton, electron (the 'beta' particle), and electron antineutrino. We can look even deeper.

The weak force is one of the four fundamental forces of nature (the other three are gravity, electromagnetism and the strong force).

Neutrons and protons are each composed of three quarks. In beta decay, one of the down quarks in the neutron turns into an up quark. This turns a neutron into a proton, and a carbon-14 atom into a nitrogen-14 atom (seven protons and seven neutrons). A key part of the process is that the combined mass of the final up quark, electron, and electron antineutrino is less than the mass of the initial down quark.

One of my goals is to understand how the weak force fits in with the other forces of nature: gravity, electromagnetism and the strong force.

We know about gravity; it has been pinning us to Earth our entire lives.

Electromagnetism is familiar; you've probably played with magnets, turning them around to push or pull each other. The electrostatic force acts on charged particles, such as negatively charged electrons and positively charged protons. Particles with like charge repel each other; those with opposite charge attract.

The weak force turns carbon into nitrogen in a process called beta decay.

6 12.011
C
Carbon

What the weak force does is amazing. You might think that the fundamental particles, in addition to being indivisible, are eternal. Untrue! The weak force annihilates heavy particles and creates lighter ones. How is this like the other forces?

If you appreciate that protons don't want to be near each other because of their like charge, then the need for the strong force makes sense. The nucleus of an atom contains protons and neutrally charged neutrons. Protons and neutrons are both composed of quarks, which are glued together by the strong force. The strong force between quarks reaches outside these particles and binds them together. This enables protons to clump together (mixed with neutrons), against their desire to fly apart from electrostatic repulsion.

There are two basic kinds of energy: kinetic and potential. Kinetic energy is associated with motion. Potential energy is associated with the fundamental forces. Gravity pulls things from high to low elevation. An electron has more potential energy the farther it is from the nucleus of an atom. There is a force pulling the electron toward the nucleus. The potential energy between two quarks grows as they are separated. The strong force pulls them back together. In all of these cases, the fundamental force drives the characters from high to low potential energy. The weak force does the same thing. From Einstein's $E = mc^2$, mass (m) is a kind of potential energy (E). By destroying heavy particles and creating light ones, the weak force is doing what the other forces do: drive characters from high to low potential energy.

∧ Aaron Webster taking a sample of wax.

The lab test result is not what we expected. It implies the wax is almost 20,000 years old. The likely explanation is that the disc is a combination of beeswax and paraffin wax. It isn't an artifact from the shipwreck.

At first I'm disappointed, but then I remind myself about the scientific method. Hypotheses are formulated and tested. Falsification is the fate of most hypotheses. The things we take as true (the laws of nature) are the hypotheses that haven't yet been disproven. When you disprove a hypothesis, you're doing science!

From oil to plastic – and back to oil?

By Samuel Page
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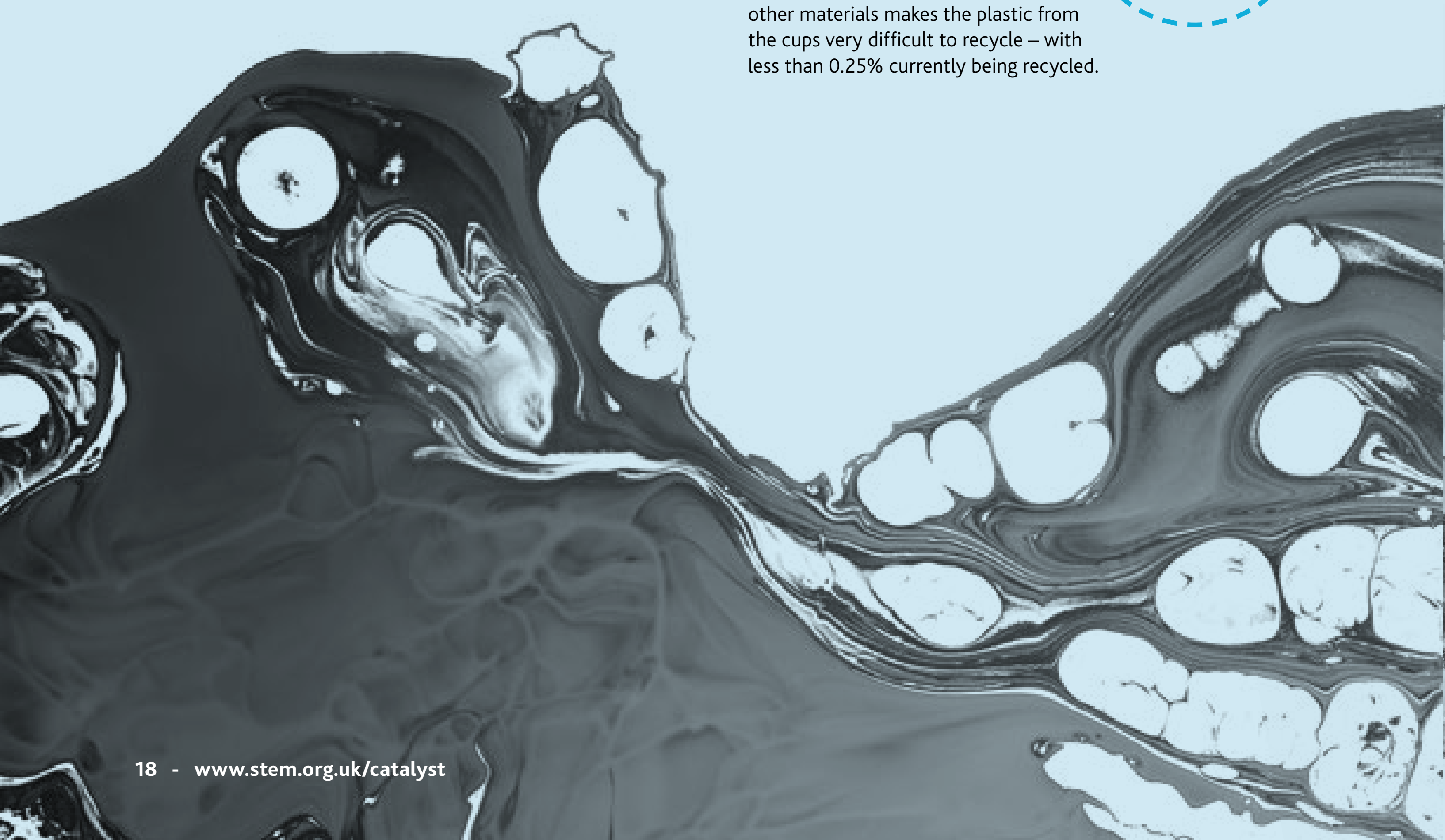
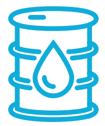
Most people nowadays understand the importance of recycling plastic items – like bottles, pots and bags – so that they can be turned into new items for further use. Of course, this is because plastics are produced from crude oil – a fossil fuel – which is a finite resource. However, there remains a significant amount of plastic waste which is difficult, or even impossible, to recycle into new products.

In fact, just 9% of all the plastics ever made have been recycled, with the remaining 91% either ending up in landfill (79%) or incineration (12%). Although the heat generated through incineration can be utilised, this process is CO2 emission intensive. Plastics in landfill are believed to take hundreds of years to decompose, and there are increasing concerns over the vast amounts of plastics entering our oceans.

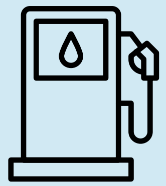
Consider the vast array of plastics that we use in our everyday lives – each has a distinct stiffness, hardness, durability and even colour. Many plastics are made of complex mixtures of polymers to combine these properties for a particular usage. To be recycled, each type of plastic needs to be separated from one another, and from any other materials in the waste stream. This is labour-intensive and technically complicated. One well-known example is disposable coffee cups, which contain an inner plastic layer to ensure that the cup is leak-proof. The binding of this layer with other materials makes the plastic from the cups very difficult to recycle – with less than 0.25% currently being recycled.



New technologies have been developed to turn unrecyclable plastics back into oil.

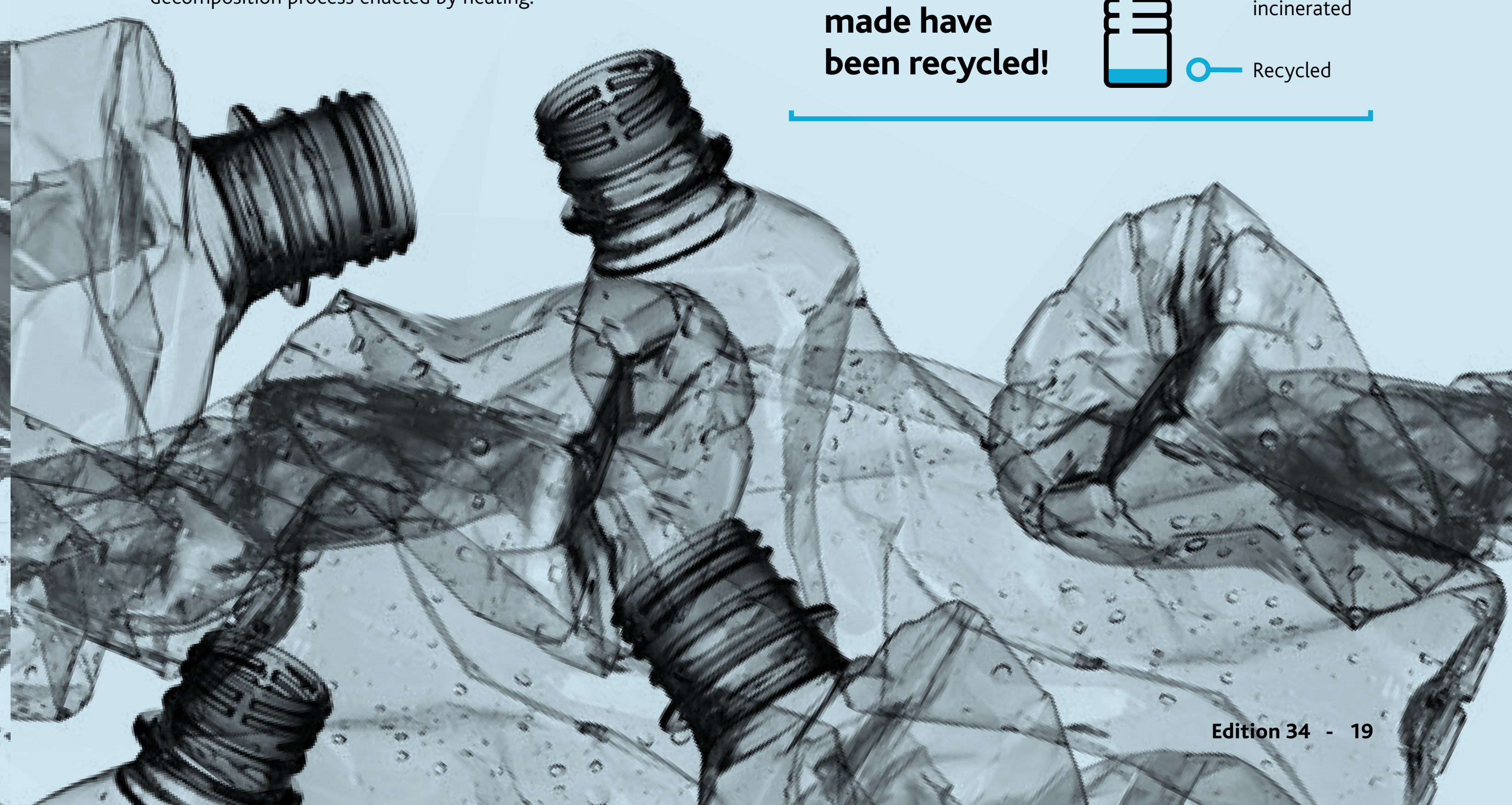


Mixed plastics are rarely recycled into new products, as they tend to produce products with inferior qualities. For this reason, recycling plants are very selective over which types of waste, and therefore which types of plastic, they will handle. This is to ensure that their processes are economical, efficient and produce high-quality products. This means that there is a huge amount of plastic waste simply going unused.



Recently, new technologies have been developed that can turn 'unrecyclable' plastics into oil, as an alternative to either landfill or incineration. Once this oil is produced from the waste plastic, it can have a number of useful futures. It could be turned into fuels or even used to produce more plastic products. After all, plastics are produced from oil in the first place.

How does the process of turning plastics into oil work? After shredding and drying, the plastic residues undergo depolymerisation under high temperature and pressure conditions. This means that the long polymer chains are broken into shorter sections. These short chains are then heated to very high temperatures (500°C), upon which the plastics break down first into a gas, and then with distillation, into oil. This chemical process is classed as pyrolysis, meaning an irreversible decomposition process enacted by heating.



It differs from incineration because it is performed in an atmosphere devoid of oxygen (therefore, avoiding burning). Whilst most of the developed processes generate crude oil as a product, some can directly convert plastic into fuels. These fuels could then be used in the home, in vehicles or in industry.

Every new technology needs to be thoroughly examined, and there is opposition to these plastic-to-oil processes. Some are afraid of the pollution such operations might create. Others state that generating petrol from plastics is not sensible, as the use of the fuels will itself generate harmful emissions. They say that we should instead focus on developing sustainable alternatives to plastics and fuels. However, whilst the world still relies on fossil fuels for the generation of petroleum and diesel, the use of waste plastics is arguably a preferable resource compared to further extraction of oil from underground. The conversion of plastic waste to oil could, then, be viewed as a short-term solution to maximise the use of the huge amount of harmful waste available, and to minimise the extraction of further fossil fuels, whilst more sustainable routes to new fuels and products are developed.

Ultimately, if plastics can be recycled, then most people would agree that is the most efficient use for them after their original purpose is over. Plastic recycling processes are continually improving, and should be expected to handle more complex mixtures of plastics in the years to come. However, there remain huge amounts of plastic waste which are not recycled, and this problem will persist. Therefore, the conversion of plastics back into oil might offer advantages over landfill or incineration, if they are carefully weighed against the environmental impact of such processes.

Only 9% of all plastics ever made have been recycled!