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The Technology Innovation Issue

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Raising the bar

simonkr/Getty

Advanced materials are winning the race in sports technology, improving equipment performance and resistance. **Andrea Gaini** investigates some of the materials gearing up for a podium finish.

During the first modern Olympic Games in Athens 1896, American athlete Billy Hoyt won the gold medal in the pole vault with a jump of 3.30m, using a wooden pole.

But as an article on *Materials and Technology in Sport* in *Nature Materials* points out, Hoyt's winning vault would "fall considerably short" of even qualifying for the Olympic Games today against the record-breaking carbon fibre poles currently in use.

Over the years, the pole vault has traversed a myriad of materials, including bamboo, aluminium and steel, before settling on fibre glass and carbon fibre, leading to the current Olympic record of 6.03m achieved by Brazilian vaulter Thiago Braz at the 2016 Games.

While athletes hone their physical abilities, materials advances are where some of the big leaps are being made.

Inside track

Nanotechnology can offer immense potential to make athletes safer, more comfortable and agile than ever.

Carbon nanotubes, silica nanoparticles, nanoclays, fullerenes, etc., can harbour high strength and stiffness, durability, reduced weight and abrasion resistance attributes.

"Their benefit is that we can use a very small quantity (typically 0.1-1wt%) for [a] great change in performance," says Dr Marion Bourebrab, a Materials Engineer at Scott Sports, Switzerland.

"Anything that came from aerospace [or the] defence sector then spreads into automotive [and] sports. Carbon fibre composites, for example…can even be found in road cycling shoes as outsoles for better stiffness…thus more power is transferred making pedalling more efficient.

"[While] graphene is highly effective in sports, thanks to its great properties overall and applicability for several aspects, in composite, [it gives] better strength, increased interlaminar shear strength, conductivity (thermal and electrical), [and is more] light-weight. In rubbers, [it gives] better grip and better durability," Bourebrab notes.

Dr Aravind Vijayaraghavan, a researcher at The University of Manchester, UK, studies graphene in running shoes for sportswear company inov-8, UK. He adds, "Graphene is the strongest material in the world and, at the same time, it has nanoscale size, so it is an excellent reinforcement filler for polymer matrices…But at present, graphene…is a niche material. So, sports offer an early point of entry for this technology, where the performance improvement is highly valued."

In collaboration with Graphene@Manchester at the University, inov-8 created the G-series – the first running shoes to incorporate graphene in the rubber outsole and the foam midsole in 2018. In the outsole, Vijayaraghavan says the material increases the rubber's strength and durability by 50%, while in the midsole, it enhances

"Anything that came from aerospace [or the] defence sector then spreads into automotive [and] sports."

energy return by 25%, helping to maintain high performance.

Vijayaraghavan explains, "This is important both for ultra-runners who might run for hundreds of kilometres in a single race, or runners who might cover long distances over a number of runs.

"The property improvements lead to significantly better grip across many different terrains, and it also increases the longevity of this grip. Similarly with the midsole, the improved energy return and optimised compression properties of the foam makes the runner go faster for longer."

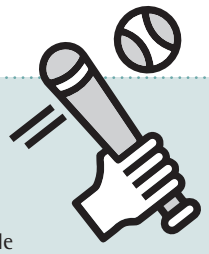
He explains that to have good grip, shoes need a soft rubber, which, traditionally have poor abrasion resistance and strength. Graphene-enhanced rubber, however, is said to simultaneously offer softness alongside strength and durability.

Vijayaraghavan bids that "the impact of graphene in sports technology is just starting to be felt, but in time, it will permeate most sporting sectors since performance gains through innovative technology is always highly sought after".

Getting into shape

Self-repairing fabrics and anti-bacterial composites are just some of the materials collectively termed as 'smart', which are predicted to play an important role in future technology.

Within sport, auxetic materials are on the radar of big brands such as Under Armour, Nike and Dainese – companies who are taken by the



Did you know?

In the USA, baseball bats got caught up in a controversial debate when new materials began entering the pitch. An article called *Materials and Technology in Sport,* published in *Nature Materials,* explains how Major League Baseball requires a bat to be made from a single piece of wood. "However, teams at lower levels from college, high school and Little League are allowed to use bats from other materials, which keep expenses low due to their improved durability. For many years, such bats were constructed of aluminium alloys, graphite composites and most recently carbon fibre composites," it says.

According to reports, as a consequence, players are able to hit the ball harder thanks to the optimised "coefficient of restitution" and the "moment of inertia".

"The new rate at which balls could be struck put players in the field at risk, especially the pitcher, who is positioned directly in front of the batter. In response to the increased potential for injury, the design of the bats must now follow a prescribed length-to-mass ratio, and bats must pass a series of performance tests to ensure compliance with the prevailing regulations," the article reads.

It explains that the latest regulation – the bat-ball coefficient of resolution – even specifies the ball exit speed after hitting the bat, which is now required to be less than half of the initial incoming speed.

"Even with the new regulations, there have been areas in the US that have banned the use of non-wood bats."

In the running

Recent findings from the World Athletics Health and Science Department confirm that high-tech running shoes significantly reduce race times for both men and women.

The study analyses seasonal best times for elite male and female runners in three race categories – 10km, half marathon and marathon races – between 2012 and 2019. The researchers reveal a statistically significant decrease in race times after 2017, which coincides with the debut of the Nike Vaporfly 4%.

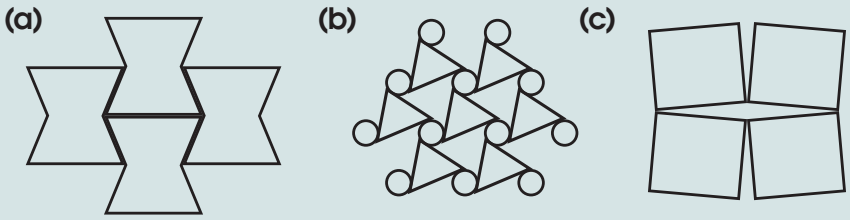
This shoe uses the latest generation of light-weight foam in the midsole, as well as an embedded stiff plate for a higher energy return. In effect, the shoe propels the runner forward with less effort expended.

"These results confirm that advanced footwear technology has benefits to the elite male and female distance runners," says Dr Stéphane Bermon, lead author of the paper. "Whether this technology will be banned or simply controlled, as it is currently, is still to be decided by World Athletics."

"Graphene is highly effective in sports, thanks to its great properties overall and applicability for several aspects."

Inov-8 Ltd

Pictured: The inov-8 G-series running shoe



Right: Some common auxetic structures: a) re-entrant structure, b) chiral structure, c) rotating squares. A version of this image originally appeared in Duncan, O. et al. (2018) *Review of auxetic materials for sports applications: Expanding options in comfort and protection, Applied Sciences* (Switzerland), 8(6), p.941. doi: 10.3390/app8060941

Credit: Todd Shepherd, Manchester Metropolitan University.

materials' unique ability to create a negative Poisson's ratio.

"This means that as you pull in one direction, auxetic materials expand in the other direction, rather than 'thinning out' as most materials do," explains Dr Thomas Allen from the Manchester Metropolitan University, UK.

He suggests the materials' application potential could extend to clothing and personal protective equipment (PPE), as auxetic materials have synclastic or 'domed' curvature that can enhance fit and comfort. Such materials are also resistant to indentation when compressed with a concentrated load, indicating suitability for impact protection, such as in helmets, kneepads or running shoes.

Most auxetic behaviours are caused by the material's macro- or microstructures, rather than its atomic or chemical structures, explains Dr Oliver Duncan, also from Manchester Metropolitan University. "There are many forms of auxetic materials – some commonly researched examples include auxetic foams, auxetic architectured cellular structures and auxetic fibre-reinforced composites. Some of these are beginning to appear in sports products."

Auxetic foams and cellular structures can have re-entrant-like cells, with inward angled cell ribs that outwardly align in tension, or fold inwards in compression. "There are many cellular structures that can cause auxetic behaviour – some common ones include re-entrant structures, chiral structures and rotating shapes (see figure above)," Duncan says. "The process of creating auxetic foams begins with compressing conventional foam to buckle cell ribs, followed by heating and cooling to fix the imposed, re-entrant like cell structure over time.

"Variants to this method exist, particularly for closed cell foam. Auxetic structures can also be 3D-printed, moulded, or cut into sheets of material."

Auxetic fibre-reinforced composites, on the other hand, can be made using standard composite fabrication methods and achieve auxetic behaviour due to the fibres' orientation.

"Auxetic fibre-reinforced composites can be made by arranging the fibres in specific configurations. These auxetic composites can have enhanced properties compared to their conventional counterparts, such as better resistance to damage under impact," describes Allen.

Duncan suggests that most auxetic sports equipment uses simple 2D shapes cut or moulded into sections of material, targeting improved product fit and enhancing comfort.

"Current concerns for sports engineers include reduction of concussion risk – highlighted by a recent UK parliamentary enquiry, and of growing concern as more people take to active travel like commuter cycling.

"Mechanical metamaterials, including auxetics, negative stiffness materials, and materials that change their behaviour during different impacts, could offer protection during a wider range of impacts than typical helmet foam. Such materials can already be found in sports helmets," he adds.

Dainese's Trail Skins Pro for off-road cycling, made from Jersey hole highly breathable, run-resistant mesh, incorporates auxetic structures.

Auxagon, the Dainese technology resulting from auxetic structures applied in the Pro Shape protectors, is said to be flexible, breathable and light. Over half of the surface is perforated to enable air and heat exchange even on the hottest days.

Top: Front view of the Trail Skins Pro protector. Minimised surface to allow extreme structure flexibility and wind flowing

Bottom: Rear view. Augmented surface in contact with the body to spread impact energy

Enhanced efficiency

While much of the focus of sports materials research has been on enhancing performance, research is now also considering mass customisation and sustainability.

Dr Mike Vasquez, CEO at 3Degrees Company, USA, a consultancy for 3D printing solutions, explains, "As an underlying material, I still think there are really interesting products being developed with carbon fibre. While this isn't a new material, the repurposing into new applications is interesting.

"Beyond the material itself, I'm excited about the potential to incorporate more complex designs into the existing material sets that we have through technology like 3D printing.

"Firstly, the potential to do customisation at mass scale. This could be done with the intent of visual customisation as well as performance customisation.

"The benefit of 3D printing truly rests in the opportunity to completely shrink supply chains that (especially in sports) rely so much on hand labour. Product production could be local since tooling is not required, and products could be produced on-demand. For many sports companies, one of their biggest costs (and waste streams) is unsold products. Rather than having a network of retailers and wholesalers, 3D printing technology could accelerate on-demand direct to consumer sales."

Vasquez suggests there is also potential in material reuse for sporting applications. "I believe there are a lot of materials that have already been processed that can be reused for sporting goods products and apparel. Specifically, used polyethylene terephthalate (PET) and Nylon are areas of interest. The trick becomes is there an energy efficient end-to-end process to make the recycling process sensical for a full product?"

On the ball

Forest Green Rovers, based in Nailsworth, UK, has unveiled a prototype football kit made from waste coffee grounds and recycled plastic.

The fabric is said to be lighter, breathable and more durable than the team's current bamboo-based kit. To put it through its paces, the club's first-team has been playing league matches in the prototype.

Dale Vince, Forest Green Rovers Chairman, says, "Our adventure in alternative materials continues. When we pioneered bamboo with PlayerLayer two years ago it was considered a pretty revolutionary idea, and the thought of using coffee grounds is no less radical or surprising.

"It's time the world of football wakes up and smells the coffee about the future of the planet. If nothing else, this prototype kit will bring new flavour to that old cliché of grinding out a result."

High impact – from rugby to the battlefield

The PROTECHT mouth guard, used to monitor and manage head impacts in rugby and other contact sports could benefit military commanders in identifying soldiers who have been injured on exercise and in battle.

The technology from UK-based start-up Sports & Wellbeing Analytics, in Swansea, deploys a number of sensors embedded within the OPRO+ Mouthguard to transmit, in real-time, to a pitch-side receiver. These sensors capture both linear and rotational acceleration.

It allows rugby coaches and management to monitor individual impacts and consider these against the total 'collision load' on a player through a match, a training week, a period block or entire season.

Thales, UK, a specialist in technology for infantry soldiers and special forces, is assessing how the product can be incorporated into communication systems and body armour worn in the field.

Gareth Williams, Vice President Secure Communications and Information Systems at Thales, says, "This R&D work could enable commanders to know immediately when individual soldiers have been injured or if there are causes for concern if somebody is not responding during an exercise or on operations.

"We potentially could know from the technology they're wearing that they've had an impact through falling, or that they've been hit. It could save lives by getting immediate support or medical assistance if someone is in trouble, for example, on a night exercise in bad weather or in hostile territory."

MATERIAL MARVELS

Second nature

From the invention of Velcro to materials systems that can reshape the way we live our lives, **Andrea Gaini** investigates the past, present and future role of biomimetics in materials science.

janzwolinski/Getty

Pictured: The burdock burr flower was the inspiration behind the invention of Velcro in 1955

In 1941, Georges de Mestral, a Swiss engineer, was walking back from a trip to the forest, when he noticed, for the first time, the unique way in which burrs had stuck to his trousers and his dog's hair. By virtue of de Mestral's curious nature, he took it upon himself to analyse the little hooked burrs of the burdock plant and the way they grasped to hair and textile.

De Mestral would spend almost 15 years studying burrs and how to recreate its characteristics and, in 1955, he finally introduced the world to one of the most widely-used products – Velcro.

Velcro is a long proclaimed example of biomimetics, so popular I considered omitting its mention in this article, however, Velcro represents just how impactful the science of biomimicry can be.

According to Dr Marc Desmulliez at Heriot-Watt University, UK, bio-inspired materials play a crucial role in advancing material sciences, providing "a new approach to see the world and utilise what will be useful for humankind".

Often referred to as 'borrowing ideas from nature', biomimetics is defined by Dr Thomas Speck – one of the leading researchers in the field based at Freiburg University in Germany – as a "re-invention inspired by nature".

Despite only being studied as a subject from the 20th Century onwards, Speck says biomimetics has always been around. "Early humans, for example, created sticks and wooden weapons…inspired by the teeth of animals.

"One of the first examples of biomimetic study is Leonardo da Vinci's analysis of flight. Da Vinci quantified nature to re-produce the bird's flight on a machine he had created."

Smartening up

Speck has been researching and studying biomimetics for over 20 years and he finds materials to be one of the most interesting applications of the lessons learnt from nature. He is now working on using biomimetics to "smart-up materials".

"[One of the things] we'd like to create with our research is materials which have embedded energy, embedded intelligence…this is our cue to soft robotics," he offers.

"If you look at robots today, for example, we have a central control unit, which more or less mimics our brain. And this can make things complicated sometimes, because of all the calculations that it requires."

He explains that the venus flytrap is one of the most valuable examples of what bio-inspired, smart materials could do. "[The] venus flytrap has a mechanical memory, it only snaps if it's triggered twice – it senses, it acts." He explains that while one single material might not be able to do all of this, a materials system that has intelligence and reactivity without the complex calculations might.

Speck is currently working on materials systems and structures for plant-inspired growing robots in the European funded project GrowBot. "Here, we use structures and materials systems found in various types of climbing plants as role models for a novel type of climbing robots," he says.

Nature is also inspiring advanced composite materials (ACM) and, specifically, high-performance fibre-reinforced composites (HPFRP).

It is an area explored by Dr Lorenzo Mencattelli, a materials scientist at Imperial College London, UK, in the paper, *Learning from nature: Bio-Inspiration for damage-tolerant high-performance fibre-reinforced composites,* published in *Composites Science and Technology.*

He notes that several biological microstructures present fibrous, hard reinforcements embedded into a soft protein matrix. This closely resembles an advanced fibre-reinforced composite material with high-performance fibres (carbon, glass, aramid, flax, etc.) embedded in a resin system (thermoset and thermoplastic).

He writes, "Despite the obvious similarity, [the] specific microstructural features and distinct traits of biological materials provide unrivalled toughness and damage resistance leading to composite structures capable of surviving in harsh environments and to preserve life and its equilibrium. Such recurrent features include staggered discontinuities, inhomogeneities, hierarchical structures built on multiple length scales and helicoidality."

"The latest evolution towards automated manufacturing signed by the advent of high-rate production 3D printing processes and automated fibre/tape placement technologies opens new avenues for the exploitation of bio-inspired solutions."

Mencattelli tells me that relatively poor damage tolerance and energy dissipation capability have been historical issues of HPFRPs, limiting their use in industry and often leading to overbuilt designs with associated weight penalty.

With the growing request for FRP composite solutions with unprecedented structural efficiency, improvement in performance is necessary to provide competitive composite designs.

"This is where nature can serve as a critical source of inspiration to develop the next generation of advanced composite materials capable of both high-strength and toughness," he notes.

To this end, Mencattelli has worked on the development of Helicoid, a bio-inspired ACM solution that has gone from laboratory to industry.

"The technology…delivers composite structures highly tolerant to impact loading…[using] structures inspired by a recurrent feature found on the protective shells of different creatures (scarbei cuticle, lobster shell, fish scale, mantis shrimp dactyl club) evolved to resist impact," he says.

Planting seeds of inspiration

Dr Mencattelli, Dr Desmulliez and Dr Speck share their favourite bio-elements that have inspired scientific inventions in materials science.

Nacre-like shells

Nacre can be found on mollusc shells (abalone, oyster, etc.) and is composed of a mineralised brick-mortar microstructure, consisting of 95% aragonite ($CaCO_3$) platelets (or tiles) and 5% organic materials.

The microstructure is organised on various length scales, from nano- to the macroscale. The key toughening mechanisms are based on tile pull-out, with one tile sliding against another, dissipating large quantities of energy through friction. This mechanism creates stable crack growth in the material, which would otherwise be extremely brittle and subject to damage localisation and catastrophic failure.

The nacre structure has been used in materials science to toughen glass, where square or hexagonal borosilicate glass sheets were bonded together using ethylene-vinyl acetate interlayers, generating a structure that allows glass plates to slide past each other. This produces a five-layered glass composite that is deformable and impact resistant, while maintaining high stiffness, flexural strength, surface hardness and transparency.

Geckos

Geckos have the ability to walk up walls thanks to small rows of hairs, known as setae, which generate several attractions between molecules on the surfaces and create a solid foothold. Engineers have been able recreate a similar effect using silicones, plastics, carbon nanotubes and other materials.

Deep-sea glass sponge

The sponge features a slender beam-like structure characterised by a cylindrical laminated structure composed of hard silica (bio-glass) alternated to soft proteins. The complex skeletons have inspired the creation of mechanically robust lattices.

You can read about how deep-water sponge offers a new take on lattice construction to strengthen bridges and buildings in *Materials World,* November 2020, at **bit.ly/2NDcW1O**

Shark skin

Inspired by the patterned diamond-like texture of shark skin, scientists from the University of Massachusetts, USA, have been able to combine anti-fouling shark-skin patterns with anti-bacterial titanium dioxide nanoparticles to produce surfaces that decrease microbial attachment and inactivate attached microorganisms.

Eleni11/Getty

Above: The nacre shell, the source of inspiration of many techniques to develop stronger materials

The damage resistance of the club depends on the highly expanded helicoidal lay-up made of thin fibrous layers. This is reconstructed by slightly rotating adjacent plies by a small angle, leading to a helicoidal distribution of fibre orientations.

"Since the applicability of Helicoid technology isn't constrained to any specific material constituents and manufacturing processes (it works with most manufacturing technologies), the technology holds the potential to bring benefits to a wide range of markets where crashworthiness, light-weighting and high performances are key design drivers," Mencattelli explains.

This could include sporting goods, aerospace, automotive, renewable energy, electric vehicles, fuel cell vehicles, rail, defence and consumer goods, he says.

Manufacturing an advantage

Biomimicry UK, a company helping to fund research in biomimetics, has found that there are over 100 institutions in the UK researching the area and its different applications. However, despite this, Speck admits that when it comes to actual impact in terms of new material production, this still floats around a shallow 1%.

"On an intellectual level, biomimetics helps us to start thinking of new materials and materials systems…On the other hand, if we look at the materials which are produced for public use, I would say this is much less."

Both Speck and Mencattelli acknowledge that the majority of the breakthroughs will come through manufacturing technologies that can reproduce naturally occurring features.

"Scalability and cost-effective manufacturing are…the key limitations for the implementation and exploitation of bio-inspired solutions into industrial materials," Mencattelli suggests.

"In my view, it all hinges on how to make sure that we harvest the information from natural products that will help fight the very large societal challenges that we are facing."

"These often require the realisation of complex structures, with limited spatial resolution. In this context…the latest evolution towards automated manufacturing signed by the advent of high-rate production 3D printing processes and automated fibre/tape placement technologies opens new avenues for the exploitation of bio-inspired solutions."

Dr Julian Vincent, Professor at the Nature Inspired Manufacturing Centre at Heriot-Watt University, UK, agrees. "It seems to me that a breakthrough necessitates the introduction of a new technique (i.e. new to the topic area) that allows phenomena to be seen in a new light.

"Unfortunately, we run into the same problem of transdisciplinary studies. Studies on hydrophobic surfaces led to a number of interesting devices, but I don't know how many products, if any, have resulted."

He says that future advances in the field will depend on the integration of biologists and technologists.

"Revolution and advantage is more likely to result from proper integration rather than technical advances. Biologists have to realise that technology is, on the whole, not particularly interested in the beauty of nature, and that the input of biology is to add another design tool for use by technology.

"In turn, technology has to realise that the comfort and convenience of reaching out for a standard answer, well tried and tested, may not be the best solution in the long run."

The future calls

Desmulliez, like many others in the field, identifies 'animated materials' as one way forward. "Animated (also called life-like) materials are the first step towards embedding information and local control without the need of a central intelligence. It is the first step towards a deeper understanding of biomaterials." he explains.

Mencattelli adds that "animated materials are really an exciting area that hold the potential for revolutionary inventions".

But terminology will have to change to adapt to the idea of creating materials systems rather than simply materials, suggests Speck. "I think there's a lot of potential in material systems [with] embedded energy and embedded intelligence."

He stresses that soft machine will be a new revolution – like the Internet – in the next 10 to 15 years. "I think [soon], everybody will have some kind of soft machine at home, perhaps they might not be called machines, but they will do stuff, interact with us…And we will [move] away [a bit] from this kind of one-central-control unit into smart materials."

Many advances are on the horizon for a field that has never stopped feeding ideas and inspiration to the world of science. Desmulliez concludes, "In my view, it all hinges on how to make sure that we harvest the information from natural products that will help fight the very large societal challenges that we are facing."

Can offshore wind farms mimic mussels' anchoring technique?

Researchers at the University of Nottingham, UK, are investigating how sea mussels stick to wet and wave-hit rocks using collagen-rich sticky threads, ending in adhesive pads known as plaques. They hope to unlock novel engineering solutions to anchor the floating foundations of an offshore wind farm to the seabed, by learning exactly how mussel plaques adapt their grip to different surfaces.

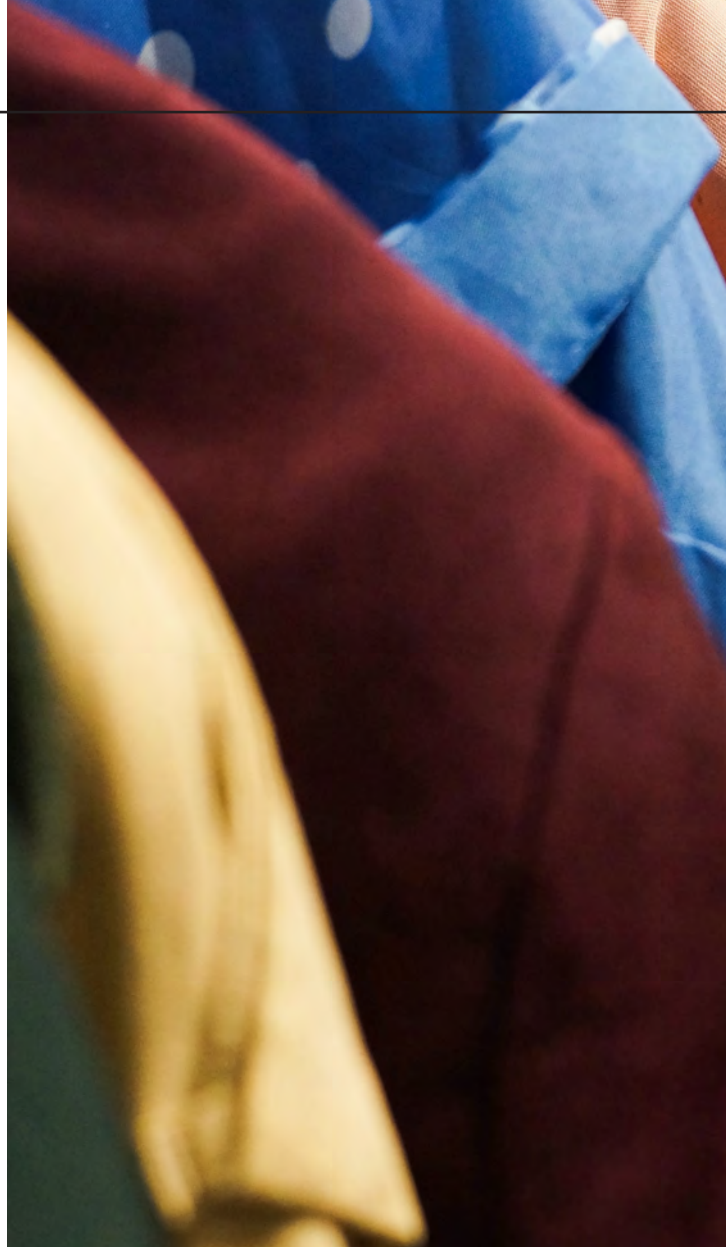
The team notes that engineers are yet to find a reliable way to fix cables from the foundation into the ground, in a system that can withstand the weight of the turbines and the forces of rough oceans and high winds.

The adhesive structure of a mussel plaque is made up of an outer, dense and protective cuticle layer and a low-density, porous plaque core consisting of a foamy network of pores at different length scales and reinforced by fibre bundles. The outer and core layers work in a cooperative way.

Existing research has demonstrated that the plaque core has good load-bearing capacity and strength under tension and shear. In contrast, man-made porous materials, such as foams or honeycombs, have very limited load-bearing capacity and strength under the same forces.

The three-year project aims to mimic the unique structural characteristics of sea mussel plaques to inform the design of new, ultra light-weight, porous, yet durable, materials. These could also find use in aerospace and transportation manufacturing.

MagicBones/Getty



Fixing fashion

How can we achieve a more sustainable fashion industry? **Andrea Gaini** uncovered the momentum behind this endeavour at a series of events.

Pollution is the broken gear in the global fashion machine, spiralling the industry's greenhouse gas (GHG) emissions to around 4% of total emissions worldwide, according to a McKinsey & Company analysis of the sector. This is approximately the same quantity as the entire economies of France, Germany and the UK combined.

At the same time, the fashion industry contributes £35bln each year to the UK economy, employing almost one million people across the country.

"Fashion in the modern-day parlance is less about keeping warm and having modesty and protecting us from the environment. It's…the most powerful non-verbal communication device that we have as human beings," said Dr Mark Sumner, Lecturer in Fashion & Sustainability at University of Leeds, UK, during an online event in March on 'Next steps for the UK fashion industry', organised by the Westminster Business Forum.

"We talk about ourselves through our clothing. And as a result of that, clothing plays a much more important psychological part in our lives than it has ever done before in history, particularly now we have the impact of social media, and we can project ourselves through those channels…It's about self-identity, it's about self-esteem."

The ball and chain

Sumner explained that when talking about fashion and its impact on the environment, it is necessary to understand the industry as a system – an industry of industries.

"The fashion industry is built on agriculture, it's built on the chemical industry. In many ways, it's very dependent on power generation in terms of minimising its carbon footprint.

"We've got spinners, we've got weavers, we've got garment factories, we've also got the retail operation, and end-of-life, we have to be aware of textile recycling – all of those industries…play a massive part in…what the fashion industry does in terms of its impact on the environment," he said.

Sumner clarified that 80-90% of the industry's environmental impacts are locked in the supply chain, and there are decisions made within that supply chain that are completely detached from the decisions a retailer or designer may make.

"We're talking about [a] supply chain where we have at least 350 million workers employed [worldwide] and dependent on the fashion industry for their livelihoods…We have fashion supply chains that will cross many sovereign borders, as [a] product is moved from the cotton fields through to its final products and delivered [to] the UK," he added.

He suggested the problem in the supply chain is incredibly complex and opaque. In order to minimise the sector's impacts on the environment, and keeping in mind its impact on communities, a systemic approach needs to be taken.

"Any solutions that we're putting forward have to take into account the complex nature of this industry of industries, [and] that even if UK Government were to take action, that action has to be mitigated and translated across different sovereign borders, to make sure that we're actually managing and working with local communities and local government."

Philip Dunne MP, Chair of the UK Environmental Audit Committee, weighed in on the discussion. He pointed to an inquiry the committee conducted, which has found that clothes consumption in the UK is a worrying waste problem during production and the end-of-life.

"We are very good in this country [at] donating old clothes to charity, we do so more than most other countries. But we also buy more, and we throw more away," he said.

He noted that British people buy more clothes compared with other countries in Europe and "336,000t [every year] are chucked into wholesale bins and end up in landfill or incinerators".

For perspective, the Empire State Building weighs roughly the same as the annual amount of clothing thrown away or incinerated.

"One policy approach, which is gaining popularity around the world as a legal mechanism to reduce waste, is through extended producer

"One policy approach, which is gaining popularity around the world as a legal mechanism to reduce waste, is through extended producer responsibility schemes. This approach involves producers bearing at least part of the cost of managing their products at the end of their life, rather than taxpayers or charities picking up the tab."

triocean/Getty

responsibility schemes," Dunne explained. "This approach involves producers bearing at least part of the cost of managing their products at the end of their life, rather than taxpayers or charities picking up the tab."

For each item placed on the market, a retailer or brand would pay a small fee that would go towards better collection and recycling facilities. Dunne put forward. "A charge of just a penny a garment on retailers could raise tens of millions of pounds to invest in better clothing collection and sorting in the UK."

He concluded, "[Such a] scheme in France has seen the number of clothing collection points triple and the amount of clothing being saved from landfill has soared. The new sorting centres that it's funded have created around 1,400 full-time jobs."

Diamonds in the rough

Professor Dilys Williams, Director of the Centre for Sustainable Fashion at the London College of Fashion, explained that small to medium enterprises (SMEs) have an important role to play.

"These designers look at a way to demonstrate adaptability and flexibility. They are, as other designers and artists in other fields, usually hands-on and really multi-talented and multi-faceted.

"They move seamlessly across a plethora of tasks and roles. But this work is seldom recognised or realised, it doesn't fit neatly into the narrow expectations of government or business criteria that are measured primarily in economic growth terms. Alongside this, government policy and business support is predominantly aimed at large entities. Anyone might think that the fashion sector is overly large businesses, the majority of conversation is about large businesses."

She stressed that SMEs represent an important opportunity for sustainable fashion as they are innovating, they have a support ecosystem that is emerging against the odds and are making progress in addressing the challenges.

"By bringing together these different elements of sustainable prosperity," Williams added, "they're not looking just at one element.

Did you know?

France was the first country in the world in 2007 to make clothing, linen and footwear companies responsible for end-of-life disposal. Any company putting new clothes on the market must either establish their own collection and recycling programme or pay a small fee to an accredited producer responsibility organisation for each garment they put up for sale.

Pictured: An industrial embroidery machine

morenosoppelsa/Getty

Fruit for thought

Presented during the Sustainable Innovation 2021 conference in March, Saucolors in Bogotá, Colombia, seeks to address water pollution while dyeing textiles.

Inspired by the colouring of blackbirds' droppings after eating elderberries in Bogotá, SauColors has created a biodesigned pigment obtained from these fruits.

The anthocyanins give the fruit its colour, specifically, cyanidin is responsible for its purple characteristic. By collecting fruit samples and using a rigorous experimentation system, SauColors has condensed its research into a mathematical formula that can transfer a stable pigmentation onto a textile fabric.

The colour manual is said to offer a local, sustainable and scalable dye alternative to replace chemical dyes that pollute water.

Fashion design entrepreneurs take a social approach to design and business, [they] are creating new models for living and working that foreground the wellbeing of their businesses and their supply chains, as well as their customers and...communities around them.

"This has increased levels of trust, job satisfaction and fair wages, and draws on traditional fashion skills, and often employs UK graduates and people who have come through the education system in this country."

Birdsong, based in London, UK, was highlighted as an example of this type of business – a social enterprise and fashion brand for people who dress in protest. Founded on the basis that consumers want more ethical and sustainable options, Birdsong was created by Sophie Slater to work "with communities who've been decimated by 10 years of austerity funding cuts.

"We work with really grassroots organisations, rather than factories, who allow their workers space to breathe, have a cup of tea, get holistic support, and most importantly, we pay London living wages and above in creating our collections of original wardrobe," said Slater.

She explained that as an SME, one of the biggest challenges they face is funding. "There's no rent controls, especially...in the high street for commercial space. But that also means that...a lot of the organisations we've worked with over the years have been forced out."

She said that another big challenge was competing with large brands who boost their search engine optimisation (SEO) online by buying up keywords that funnel users to their sites when searching for sustainable ethical fashion.

"We're also paying the same rate in tax as every other brand and something I would suggest is tax breaks for companies with proven and real core, social and environmental contributions."

Ryan Mario Yasin is the founder of Petit Pli, a fashion SME based in London, UK, which creates garments that 'grow' to fit children from new-born to four years of age. He spoke about funding for SMEs at another event on fashion sustainability, 'Fashion Comes Full Circle: Redesigning a Sustainable Future Through International Collaboration' organised by the Knowledge Transfer Network (KTN).

Yasin participated in Global Expert Missions to US and Paris, which analysed different approaches to sustainable fashion. Reporting on this experience, he said that compared to projects like Station F – a French start-up campus – the UK needed a more centralised approach to funding and support for SMEs.

"Station F centralised all the information for those businesses that are going through the same issues in one place and makes things much more efficient," he explained.

"I think if we found a way to bring all this together [in the UK too] perhaps the funding could be used slightly more efficiently."

Stemming the flow

Coming back to the concept of circular economy, this idea became much more well known after the European Union adopted it as the future of European economies.

"At that time, it was often presented in the context of increasing recycling, and to a degree, keeping in circulation for longer things that are already in the market," explained Professor Tim Cooper, Head of the Clothing Sustainability Research Group at Nottingham Trent University, UK.

"And what's necessary now...is that for the circular economy to be implemented fully it has to go right back to the stage of design. So, it's not just the need to understand how to reuse and repair, but also how we design the system.

mtsow/Getty

vannaweb/Getty

"A circular economy would slow down the consumption of new products, reduce the demand for virgin materials and therefore help cut the carbon emissions and water footprint associated with the primary production of textiles."

"I like to think of the circular economy not closing the loop...[but] about slowing the flow. Essentially, it's about generating more value from the same amounts of material, recognising that vast amounts of value are lost."

Cooper talked about the issue of embodied carbon. "In garments in particular, when one is recycling, one is using carbon again to break down the use of material into constituent fibres then remaking the fabric into new garments. Whereas reusing the fabric is a way that reduces that energy impact."

Over the last eight years, the UK Waste and Resources Action Programme (WRAP) has worked with the sector through the Sustainable Clothing Action Plan, to reduce the carbon, water and waste footprints of clothing sold in the UK through improvement actions e.g. choice of fibre, amount of clothing collected and reused. Signatories also sought to influence consumer behaviour through the *Love Your Clothes* campaign.

"Through collaborative action, our brand and retailer signatories have reduced the carbon footprint of new products sold by nearly 16% and reduced their water footprint by nearly 20%," said Catherine Salvidge, Sustainable Textiles Sector Specialist at WRAP.

In April this year, WRAP launched Textiles 2030, a voluntary agreement presenting ambitious targets to reduce the industry's carbon emissions by 50% by 2030, in line with the 2016 Paris Agreement, as well as decreasing its water footprint by 30%.

Textiles 2030 focuses on three areas of circularity that will deliver impact savings through industry collaborations.

Salvidge added, "Firstly, [we] will be designing products to the principles of circular economy. So that products are designed to be used more [and]...reused, repaired and finally recycled at the end of their life.

"Then [we will] also focus on how we can make circular business models the norm, through increasing the amount of clothing acquired through models such as reuse, rental and subscription, and how we can influence consumer behaviours to adopt these business models and more responsible consumption habits.

"And then finally, looking at how we close the loop on materials...This will involve bringing the whole textile value chain together to accelerate the ability for fibre-to-fibre recycling in the UK, and also to drive the demand for cycle fibres from brands and retailers."

Ultimately, the goal Salvidge says is "that a circular economy would slow down the consumption of new products, reduce the demand for virgin materials and therefore help cut the carbon emissions and water footprint associated with the primary production of textiles".

Out of fashion

93bln m^3
of water used worldwide in textile production each year

1.7Bt
of greenhouse gas emissions emitted in global textile production in 2015

26%
of the world's Carbon Budget will be used by the fashion industry by 2050

¼
of the industry's resources are wasted in fabric leftovers

£140mln
worth of clothing goes to landfill each year worldwide

160Mt
of clothing will be produced by 2050 per annum globally

Source: British Fashion Council

Message in a bottle

With COP26 approaching and environmental targets becoming more pressing, a Westminster Forum event discussed some of the policies being proposed to deal with the UK's plastic waste. **Andrea Gaini** reports.

In 2017, the UK processed 3.4Mt of plastic waste with roughly a third going each to incineration, landfill and recycling, according to a UK Research and Innovation (UKRI) report entitled, *The 'P' word*.

It reads, "The limited recycling capacity of the UK meant that only 0.4Mt of the total 1.1Mt sent for recycling, was processed locally. The remaining 0.7Mt of 'recycled' plastic waste was sent overseas, yet, with little assurance that recycling was actually undertaken in these countries."

During the Westminster Forum event 'Next steps for tackling plastic waste in the UK,' experts discussed some of the ways the UK is addressing the problem.

Extending responsibilities

Steve Palfrey, Chair of the Association of Directors of Environment, Economy, Planning and Transport (ADEPT) Waste Group noted that, "There's an Environment Bill working its way through...Parliament at the moment which includes a number of key measures to deal with improving waste management in this country."

Palfrey explained how Extended Producer Responsibility (EPR) is one of the key tenets. According to this policy, "the brands that are producing these products that result [in] packaging waste, [would] have [a] real skin in the game in terms of ensuring the right environmental outcomes for that material.

"That [would] drive up both the quantity of material [that] is recycled, but also focus industry on reducing the quantity of material that's used...and on product design to increase recyclability, because that's how industry will minimise its costs in terms of dealing with packaging waste."

He explained that EPR may help tackle a bigger issue "which is that, at the moment, our economy doesn't really factor in the environmental costs of dealing with waste and dealing with products we buy.

"But it will also help fund improvements in recycling systems, higher capture rate, more consistent systems across the country, to capture a wider range of materials.

"The other part of EPR is that it means that the brand will care what the public do in terms of the packaging waste that they have...because it will have a direct financial impact [on them] whether people recycle, whether they litter, whether they put their material in the refuse."

Barry Turner from the British Plastics Federation, UK, added, "We've done an awful lot of work on design guides, but EPR...must actually drive the right outcomes. And by that it's got to drive lower climate change. And, at the moment, EPR makes a passing reference to [reducing climate change], but we're yet to see that it's sort of embedded in some of the basic principles."

Turner also addressed what he noted as a cultural issue of littering. "There are also outlines of proposals as to how producers will also be required to contribute towards the cost of littering [because] we have an issue in this country, and we need to address it. And it's not just a case of passing the buck for who actually covers the cost. It's an issue of re-education. It's an issue of changing people's attitude."

Taxing times

Palfrey and Turner discussed the key role that the new Packaging Tax (set to be implemented from April 2022) will play in the development of a circular life-cycle for plastics.

The tax will be applied to plastic packaging produced in, or imported into, the UK that does not contain at least 30% recycled content. It will affect UK producers, importers, business customers of producers and importers, and consumers.

Palfrey explained, "That's really important...[It could be] a real game changer in terms of driving markets for plastics recycling, and the economics of plastics recycling."

Turner, on the other hand, noted that the tax needs to evolve. "It is a bit blunt. It doesn't incentivise improvement. And, I too, would like to see, as we move forward with the tax, that it does evolve and becomes a smarter tax.

"I'd also like to [see] that the money raised through the tax [is] directed to help us build a world-class recycling system in the UK. For too long, we've been dependent on exporting far too much of our waste. And that's whether it's plastics, textiles, etc. We've got a golden opportunity here to turn the dial back and build a greener economy in the UK.

"And as part of that, I think we're missing a bit of a trick if we do not put some sort of target in place going forward to gradually reduce and wean ourselves off our exporting of plastic waste."

Returning packaging

Lewis van Diggele, Public Affairs Manager at the British Soft Drinks Association, UK, explored the possibilities presented by the upcoming Deposit Return Scheme (DRS).

"In a nutshell, [it] is all about incentivising consumers to do the right thing and…return their containers. So that we can get a clean separated stream, and hopefully get a circular system going to turn this [material back] into new packaging," he explained.

"If we can do that, it will boost our members' ability to put increasing amounts of recycled content into their packaging, and it will reduce our reliance on virgin materials. So, a win for the wider environment."

Orla Woods, Senior Consultant at Eunomia Research and Consulting, UK, added, "Deposit systems are primarily introduced to increase the recycling rate of beverage containers…[and] can achieve return rates over 90%.

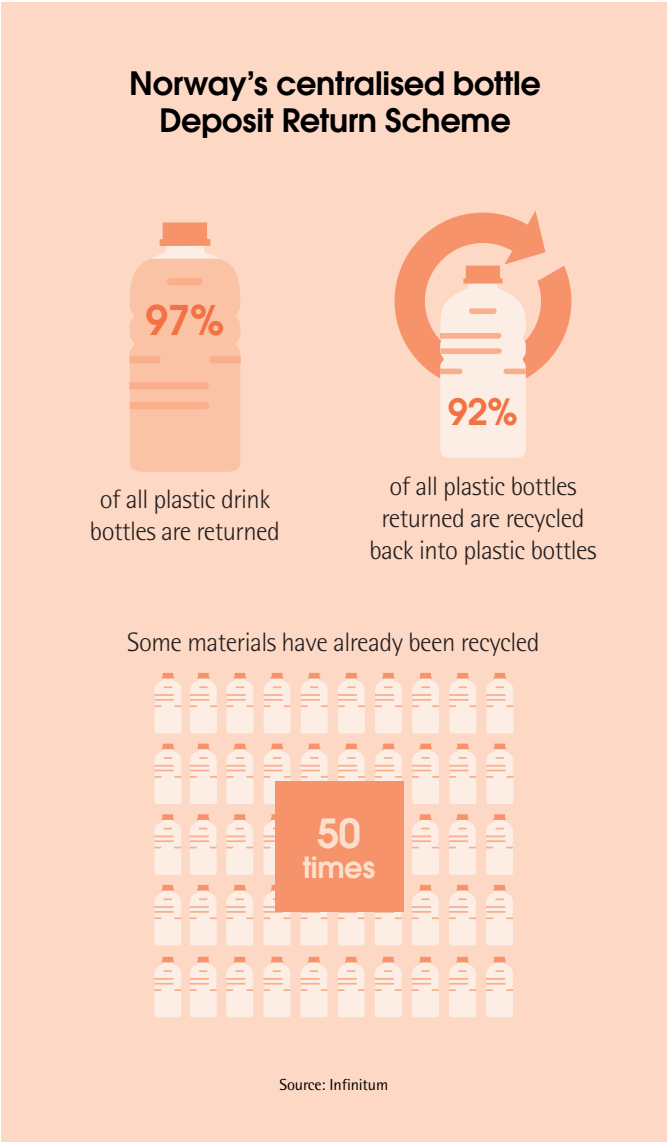
"A well-defined single-stream collection reduces contamination and provides food-grade, recycled material that can be used to increase the recycled content of new beverage containers."

Woods also explained that these systems can help reduce littering by a third. "There are then [other] additional benefits. For instance, we estimated a few years ago [that] a DRS in the UK could create more than 4,000 jobs, and the increased recycling and reduction in landfilling and incineration also reduces greenhouse gas emissions and other air pollutants."

She explained that to realise these potential aims, it is crucial to get the operation right. "High-performing systems…have a single centralised deposit system operator that is owned by the beverage and retail industry.

"Businesses need some control over the system…and we need the whole industry to work together. And this approach also promotes accountability, transparency, and it's more efficient and pleasant and achieving economies of scale.

"The government's role is then limited to oversight and scrutiny. It's important that they set statutory targets. But it's best to avoid specifying too many details in legislation, as this prevents the system from adapting and evolving over time."



Beyond recycling

Despite recognising the importance of recycling, some panellists argued that there is too much focus on recycling over reducing and reusing waste.

"Despite the rhetoric, I'd say that the government hasn't yet even taken advantage of the low hanging fruit and the easy opportunities to get rid of some of the…avoidable waste," said Libby Peake, Head of Resource Policy at Green Alliance, UK.

"And the example that you see here is about the… microbeads ban that the government brought in. They brought it in in 2018 and they're still talking about it. The Queen's Speech described it as one of the world's toughest bans on microbeads in rinse-off personal care products in 2018. [And] I think the key bit there is that it is very limited. It's only on rinse-off personal care products.

"Rinse-off cosmetics account for a very small proportion of intentionally added micro-plastics, they're less than 10%. So that leaves a very large amount of intentionally added micro-plastics that still find a way into the open environment that the ban hasn't tackled. The EU has actually legislated through its chemicals legislation to bring in a much more ambitious ban… preventing more than 90% of intentionally-added micro-plastics from reaching the environment."

IOM3 has submitted written responses to the Extended Producer Responsibility (EPR) for Packaging and Introducing a Deposit Return Scheme (DRS) in England, Wales and Northern Ireland consultations. Over 10 weeks, IOM3 worked with nine partners to deliver a series of cross-supply chain collaborative webinars, hosted an online event looking in more detail at the materials specific aspects, and heard members' views through a series of workshops and surveys to best inform its responses. Find out more at ***bit.ly/3xejpkh***

Also see Materials World, February 2021, for an article that plots packaging's journey to sustainability from the IOM3 Packaging Society at ***bit.ly/37h8jR0***

On the horizon?

Reporting on the event, 'Next steps for developing the UK nuclear sector and delivering new build projects', **Andrea Gaini** explores the market challenges ahead.

Phil Silverman/Shutterstock

Pictured: The nuclear power stations of Sizewell A and B in Suffolk, UK

"Nuclear [power] is a fundamental step for all of us in ensuring that we build assets that are clearly needed by our economy...for the world we're going into, which is [trying to] deliver net-zero," said Humphrey Cadoux-Hudson, Chief Executive at Sizewell C, a proposed new nuclear power station to be built in Suffolk, UK.

Speaking at a recent Westminster Forum event on the future of the UK's nuclear sector, he said, "At the moment, this effort is being driven by wind and solar...[as] a way of reducing the cost as we drive down CO_2 production, displacing coal and gas. But there comes a point in the modelling, when you do that, that you start having an overarching cost of creating a stable system. And that really points to the role of nuclear...combating intermittency by replacing it with a stable baseload power production."

He continued, "I think there is now, amongst people modelling the electricity system, a fair amount of consensus on the need for low-carbon baseload, as [we] try and get down to zero.

"There are two potential sources – nuclear and carbon capture and storage. But at the moment, carbon capture and storage is an experimental technology, we have no large-scale facilities to test, firstly, whether they really are net-zero, and secondly, whether they're sufficiently reliable to be part of the system."

A nod to innovation

Mark Foy, Chief Nuclear Inspector at the Office for Nuclear Regulation, noted that regulators have an important role in facilitating a thriving nuclear sector. He reflected that the industry is considered by some as being overly conservative, lacking innovative thinking, and often relying on tried and tested solutions.

"But this wasn't the case when the industry was born in the 50s and 60s – the industry has to provide an environment for new technologies to flourish over doing things differently, leading the way but also learning from other industrial sectors such as aviation, space, rail, oil and gas, and how they have used technology to their advantage.

"Regulators have a critical role here in helping industry to work in ways that are safe, sustainable, and which offer [the] best value...in the interest of public safety, but also in the interest of advancement and progress."

He added, "I think that we all recognise that the sector's ambition and project delivery cannot be successfully achieved without new, innovative, more effective ways of doing things. And as regulators, [we have an] important role in creating and sustaining the conditions where projects can flourish, facilitating the adoption of new ideas, approaches and new technologies where it is safe to do so.

"Our aim is to reduce regulatory uncertainty and avoid undue burden to remove unnecessary barriers to progress – even if these barriers are real or perceived in many instances. Our commitment to embracing innovation is formalised in our own 2025 strategy. In practice, this means supporting industry to realise the benefits of new technology and novel approaches by providing a stable but progressive regulatory environment."

He argued that industry and regulators alike "mustn't shy away from opportunities that have been presented by these new technologies because they seem too difficult, and we must avoid fostering a culture where we are seen to be risk averse".

Foy added, "Last year, we published our approach to regulating innovation, which provides clarity on how our enabling approach extends to innovative new projects within the nuclear sector, setting our commitment to ensure our regulatory systems remain flexible and outcome-focused to enable innovation and disruptive technologies to thrive."

Backing for small reactors

The UK Government is backing the development of the world's first Small Modular Reactors (SMR) with £210mln in new government funding for the Rolls-Royce SMR.

Matched by private sector funding of over £250mln, the investment will take forward Phase 2 of the Low-Cost Nuclear project to further develop the SMR design and take it through the regulatory processes to assess suitability of potential deployment in the UK.

Supporters of SMRs say they have the potential to be less expensive to build than traditional nuclear power plants. The modular nature of the components offers the potential for parts to be produced in dedicated factories and shipped by road to site – reducing construction time and cost. Rolls-Royce estimates that each SMR could power one million homes – equivalent to a city the size of Leeds, in the UK.

The role of ESG

A report from the Generation IV International Forum (GIF), *Nuclear energy: an ESG investable asset class*, found that nuclear has the ability to report at least as well as, or better, than other energy sources when it comes to Environmental, Social and Governance (ESG).

It reads, "Key to reporting is ensuring that companies and projects are established to the highest standards, as the industry generally does, but there is also an obligation on the investor community to ask all energy companies to report on the wide range of ESG to make sure all projects are considered on a consistent open and transparent basis.

"Nuclear projects are vital to countries meeting their nationally determined contributions (NDC) and net-zero commitments. The investment community has an obligation to ask companies to report in consistent ways to provide nuclear the opportunity of accessing climate finance and making nuclear an investable asset class."

Building investor confidence

"The decarbonisation of the economy and objectives [to] achieving net-zero are clearly going to take a substantial level investment... The role of the private sector...in achieving that zero is critical," said Darryl Murphy, Head of Infrastructure – Real Assets at Aviva Investors, UK, while discussing the prospects of attracting more capital to the nuclear sector.

"There's a large amount of capital available across the relevant sectors, in many cases, subject to the underlying risk profile of those investments. So, that capital is readily available for established technologies, certainly, such as wind and solar, but investors are increasingly having to consider how they will mobilise that capital for other technologies, such as hydrogen, carbon capture utilisation and storage (CCUS), and how those markets will develop."

Murphy explained that the nuclear sector is historically one that has struggled to be considered in the investment market. This is due to a lack of policy design and efforts to make nuclear an attractive asset class.

He argued the sector becomes infinitely more investable if the government sees nuclear as a key component in the net-zero energy strategy and there is an Environmental, Social and Governance (ESG) case for nuclear – something which most companies now look for in every investment.

The Generation IV International Forum (GIF) recently published a report that addressed this issue (see box-out above). Murphy summarised, "It importantly set out a framework that financial investors could utilise, to assess ESG from a nuclear point of view. The ESG case for nuclear is critical if the large-scale capital required is to be mobilised...Without that ESG case, the detail on contractual and regulatory aspects will be frankly, irrelevant...This is not about government selling the answer to financial investors, it's making sure that investors have the right data and background in terms of policy and support, both from a government point of view and from developers, so they can make their own informed decision."

The report recognises, Murphy explained, that investors have exclusionary criteria around nuclear energy and that the UK Government will not finance any nuclear energy-related expenditures under the framework. "I think the concern [this] raises is one of how clear the support...within governments [for nuclear] is," he argued.

"A further concern is whether nuclear will be included in the... UK green taxonomy". He noted that while these taxonomies were not definitive in their importance, "any exclusion of a technology is not going to be positive in any independent assessments, it will arm the case against the particular technology.

"I would like to see greater public engagement on nuclear by governments...it's a topic that many politicians don't want to discuss".

Also see Materials World, March 2021, for an article on the role of materials in the energy mix, including materials innovation for the safe operation and life extension of nuclear plants, at bit.ly/MaterialsInNewEnergy.

Nuclear power stations in the UK

UK's nuclear numbers

16%	of electricity was produced through nuclear power in 2020
13	current operable reactors
1	nuclear plant under construction - Hinkley Point C
32	reactors have been shut down
Half	of the current nuclear capacity is expected to be decommissioned by 2025

Source: World Nuclear Association/UK Parliament


Skyhobo/Getty

Framing mineral resource governance

By Andrea Gaini

As the world gears up for a green recovery, calls grow stronger for a new framework of mineral resource governance to tackle issues such as sand and mine tailings management – topics explored at a recent webinar organised by the UN Environment Programme (UNEP) and the Green Growth Knowledge Partnership.

The UNEP's report, *Mineral Resources Governance in the 21st Century,* explains how minerals underpin global development and are critical to achieve the UN Agenda 2030 and its Sustainable Development Goals (SDGs). This could translate into copper that wires communication, lithium and cobalt fuelling the global transition in electric energy, or the garnet that filters water.

The publication cites how the demand for minerals is being driven by climate change and the renewable energy transition. Graphite, lithium and cobalt, for example, are expected to experience significant production increases by 2050 to meet the growing demand.

However, Antonio Pedro from the UN Economic Commission for Africa, one of the report's lead authors speaking at the event, noted that, "[The governance framework at the moment] is a spaghetti bowl with many actors, divergent interests, power asymmetries, several unfinished businesses and new hot spots, which impair our ability to make constructive change".

He called the issue a "joint responsibility" anchored around respect of planetary boundaries and achieving resource efficiency, a circular economy and life-cycle analysis.

Elephant in the room

"15Bt of sand are used every year, it's the second most-used resource in the world after water", said Louise Gallagher, Environmental Governance Lead at UNEP/GRID-Geneva Global Sand Observatory Initiative. "And yet, it is not featured or accounted for in the current mineral resource governance framework."

Construction is the biggest sector for sand usage, but it is not the only one, as high-quality sand, in the form of silicon, is heavily used in technology.

"The extraction of sand is what is most worrying as it is having an impact on rivers, beaches and marine water," Gallagher continued. "It is changing our biodiversity and eco-system integrity that could have an impact on fisheries and climate resilience."

She argued that the lack of acknowledgement of sand in mineral resource governance is perpetuating a storyline that is no longer true. "We've been telling ourselves that sand is cheap, and available and free, but that might be true in geological times, but not in human times."

Tackling tailings

The issue of mine tailings' management has been a prominent topic of discussion for many years, heightened, more recently, by the dam failure in Brumadinho, Brazil.

Franziska Hirsch, from the UN Economic Commission for Europe, said, "The increase of mineral resource extraction to produce the clean energy technology to be able to limit climate change also means an increase in hazardous waste which needs to be stored in more and more tailings. Safety must thus be a priority and we cannot continue business as usual."

2020 marked an important milestone in this direction as UNEP, the Principles for Responsible Investment and the International Council on Mining and Metals, launched the *Global Industry Standard on Tailings Management.*

Aidan Davy, Chief Operating Officer and Director of the Environment Programme at the ICMM, shared that the Standard aims to achieve the ultimate goal of zero-harm to people and the environment, covering the entire tailings life-cycle from site selection through to closure and post-closure.

"[The Standard] elevates accountability to the very highest organisational level and establishes very clear expectations around what transparency in disclosure should look like," he added.

As the Standard comes into force, supporting it will be the next challenge. Angela Kariuki, a Law Officer at UNEP, agreed with other speakers stating, "The next step to support the global tailings management standard's implementation is to establish an independent international institution that is self-sustaining, acts as a knowledge hub of best practice and reflects a multi-stakeholder process in order to ensure the highest levels of transparency and an identifiable degree of independence from the mining industry."

Also see Materials World, July/August 2020, for an article on Tailings: are lessons being learnt? And listen to IOM3 podcasts on responsible mining at bit.ly/IOM3-Investigates-Podcast

Extracting potential

If managed well, the extractive sector can play a positive role in promoting broad-based development and structural transformation of economies, notes the report, *Mineral Resource Governance in the 21st Century/UNEP.* Key points include:

- **Poverty eradication** – Mining generates significant revenue streams through taxes, royalties and dividends for governments to invest in socioeconomic development.
- **Clean water, sanitation and life on land** – Mining requires access to land and water, which gives rise to significant and wide-ranging landscape impacts that must be managed responsibly.
- **Affordable clean energy and climate action** – Mining activities are also energy- and emissions-intensive in terms of the production and downstream uses of mining products.
- **Decent work and economic growth** – Mining can alter the lives of local communities, offering opportunities for jobs and training, while contributing to economic and social inequities if not appropriately managed.
- **Industry, innovation and infrastructure** – Mining can help drive economic development and diversification through direct and indirect economic benefits, development of new technologies and the construction of new infrastructures.

The research melting pot

How do we evolve our research culture to optimise academic environments? **Andrea Gaini** attended the first EuroScience Policy Forum which sought to tackle the debate.

The last 18 months have shone a light on the pivotal role that scientific research plays in our lives, not just in the development and advancement of technology, but also for our survival. As such, it seems fitting that the first EuroScience Policy Forum sought to examine the effectiveness of our research culture to build on these successes, with a workshop entitled, 'A new research culture for sustainable academia'.

"Cultures in general, all types of cultures, are based on values… And research is no different," mused Dr Sean Sapcariu, Programme Manager at the Luxembourg National Research Fund (FNR).

"And in research culture, there are values, I would argue, at [the] individual level – so the values you hold dear for yourself – [as well as values] in your group, in your department, institution, country, region, global…And some examples of these values would be integrity, openness and open science principles, collaboration, excellence, academic freedom, creativity, development of individuals, and many more.

"Many times, these values are tied to the strategy, the goals, the vision of the group, the institution, the department, the country. [These] values are also…underpinning the evaluation for hiring, promotion and grants – so how well does the application fit the quality of excellence, innovativeness, novelty, impact, and all these sorts of things?"

Sapcariu argued that there are two main issues that need solving when reflecting on such values. "[The first is that] we have been using the same values for a very long time…but they've not really been expressed," he said.

"And having these implicit values has worked for a long time, lots of great research has been done over…many years. But now that we're bringing research culture into the spotlight and wanting to improve it moving forward, we need to be more explicit about the values underpinning this culture [and] define them."

The second issue, he explained, is defining these integral values. What does excellence, quality, or impact actually mean?

"If you define excellence as paper output…that leads to a very different culture than if excellence is how good of a teacher and mentor you are [and] how good you are at engaging with the public.

"We need to identify, define and align on these values within and across the scales. And this is a fundamental step towards building and defining a research culture that balances the needs and expectations of the scientific community, while achieving the goals of the institutions in the larger research ecosystems."

He suggested that this needs to be achieved in a combined top-down and bottom-up manner. "[As] funders, institutions and policymakers, we need to engage everybody in the research community to design a research culture around these shared values and goals that we see as important…for the future.

"But at the same time, [the values] should be revisited every five to 10 years…For example, open science 10 years ago was non-existent, and now it's a very, very hot topic. So maybe in 10 years, it'll be so normal that nobody will think about it anymore, and we will need to move on to the next thing.

"Doing this will [also] help institutions and funders…know what values researchers deem important. [And] they should have a say in how they should be evaluated…[so that it feeds] into the development of evaluation criteria for hiring, promotion, grants, etc."

He added that working together in creating and updating an explicit set of shared values would help improve research culture and evaluate and reward researchers for the right things, ensuring that research remains an attractive career choice for people throughout Europe and the world.

Building bridges

Professor Ulrike Felt, Head of the Department of Science Technology Studies at the University of Vienna, Austria, discussed the relationship between the research community and wider society.

She talked about how research is organised around temporary projects and some of the challenges that this structure can pose. "Research is virtually only organised by projects, which means that we have this constant rupture, a kind of performance [pressure]. And we have to think if the way we fund research is the cleverest way to do that, and that has a lot to do with society," she said.

"In the pandemic, this was a moment of learning…when in the beginning, everybody expected science to give the responses to the problems we have, [and fast]. And we had to learn that science doesn't get fast responses…We're not always sure what [scientists] know. And I think this came about [from] a very raw misunderstood relationship."

She suggested that if communicating science is only about selling it to society then this is a "very unhealthy relationship" that does not engender a stable and robust culture where research can flourish. "And I think we're doing the mistake [of selling]…science as being fast and perfect."

"If you define excellence as paper output…that leads to a very different culture than if excellence is how good of a teacher and mentor you are [and] how good you are at engaging with the public."

Empowering researchers

Professor Günter Ziegler, President of the Freie Universität Berlin, Germany, noted that universities can empower researchers through three key elements – freedom and trust, time and money.

"Freedom and trust come together – freedom to pursue new, radical, non-standard, high-risk, challenging ideas…[and] the ones that are not guaranteed to work out. That freedom to try things out is absolutely important in order to be able to thrive.

"That also means…freedom from external, unscientific, short-sighted metrics, freedom from evaluation," he added, highlighting the importance of passion-led fundamental research.

He stressed that trust, on the other hand, needs to come from transparency. "There has to be [some] sort of meritocratic criteria for career paths. Researchers need to feel that they can trust the system to offer them a fair and transparent career path."

The issue of time, Ziegler continued, deals with questions of policy, research funding and the duration of grants and contracts. He said that these need to match the scientific tasks.

Grant durations in Germany, for example, are typically too short he said, and often shorter than they are in other European countries. Research times are often disrupted by administrative burdens, such as writing applications and grant requests, and do not take into account time away from the research. "If you want researchers to thrive, they do need breaks, they do need weekends, they perhaps need sabbaticals [and] this time has to be in the system."

Ziegler noted that money is key to unlocking time. "Research can only work in these times with sufficient grant money, and money for infrastructure, for buildings, for digital transformation…We don't have enough basic funding for science and the universities are under-funded, and that means that they depend too much on project money.

"One lesson from the pandemic [is that] one has to invest in the universities, into basic funding, to start things…The future is shaped by research and innovation…so that means the funding has to match the size of the challenges."

The World Economic Forum's seven steps for promoting better research culture

- **Open communication**
  Giving researchers the chance to share their successes as well as their 'failures', and offering support when things do not go right. This dispels the assumption that senior academics have had continuous successes.
- **Creating a support system**
  Providing and promoting career counselling, coaching and support services, which may help to reduce pressures within a research environment and promote wellbeing.
- **Consensus on behaviours and attitudes**
  Researchers could develop a group pledge so all team members are aware of what is expected in the research environment.
- **Sharing best practice**
  Encouraging researchers and support staff to find time and space to meet to share ideas and experiences. By involving other departments, institutions and sectors, discussions can focus on improving research integrity and culture, to share best practice on what has worked, what has not and its impact.
- **Leading by example**
  Organisations, department and team leaders are at the forefront of promoting a positive research culture by taking part in training, encouraging discussions to address difficult questions in an open and honest way, and by having an open-door policy.
- **Discussing training gaps**
  Researchers can feel more valued if skills needs are reviewed individually and as a group, ensuring they all possess the necessary skills for their role, such as statistics, data handling, proposal writing and resource management.
- **Embedding culture at the institutional level**
  Hosting a research culture and integrity day could be a way of highlighting its importance and engaging all staff across the organisation. Presentations, workshops and panel discussions could be given from across the organisation. Different departments could showcase the ways they have improved research culture and integrity, as well as addressing areas where there is still room for improvement.

Copper production in symbiosis

By Andrea Gaini

"Industrial symbiosis is the process by which discarded resources are captured, recovered and used from one industry or operations by another industrial operation, traditionally taking place between separate industries operating in close proximity," explained Dr Alain Vassart, Secretary General of the European Battery Recycling Association. He was speaking at the event, *Opportunities for Industrial Symbiosis in the Copper Industry,* organised by the International Copper Association (ICA).

Recent research, conducted by design, engineering and management consultancy, Arcadis, UK, reveals how industry symbiosis has the potential to increase the use of copper at the end of a product's life.

The study points to the repurposing of electric vehicle (EV) batteries at end-of-life as a means of retaining approximately 70-75% of their economic value, as an example. EVs use roughly up to four times more copper than an internal combustion engine vehicle. Their batteries could be repurposed for stationary energy storage, including grid, residential storage and commercial, renewables and thermal generation, further prolonging the use of the copper.

Vassart, however, pointed out that there are some key factors for achieving industrial symbiosis. "The first one is that you need to extract a specific by-product from your process with a desired quality or specifications that will fit a market, and then you need to find a market for it.

"Once you have this, you can try to create the industrial symbiosis by checking if you have a solid business case. That means if you can [prove that it] is a profitable operation for both the producer of the resource and the user of the resource."

He also outlined the need to think 'outside the box' and find a fitting place for end-of-life products in other industries, and the importance of geographical proximity and favourable legislation and policy.

Olga Pozlevič, from the Directorate-General for Internal Market, Industry, Entrepreneurship and SMEs in the European Commission, added, "In 2019, in Europe, we adopted the new growth strategy, the so-called European Green Deal, [which aims to make] sustainability the means to all policies," she said.

"So...we are going to change the way we consume, produce, build, invest and educate in almost all policies.

"[The Green Deal] is the first cornerstone and the second came in March 2020, when...we put the focus also on the pre-production phase, the pre-consumer phase. So, it's not only about recycling, and bringing back the materials after the use of the product, but it's also about closing this industrial cycle, the pre-consumer cycle. So, this is the industrial symbiosis effect that we're talking about."

Pozlevič explained how the *European Circular Economy Action Plan* includes two chapters that focus on industrial symbiosis.


Funtay/Shutterstock

"The first one is [on] the circular production processes, where there is a mention of the revision of the Industrial Emissions Directive... it's been realised that the current... directive does not have enough focus on circularity and resource efficiency."

One of the options to fix this, Pozlevič argued, was to introduce national plans for industrial symbiosis such as the one in France to count the amount of symbiotic transactions.

"The second chapter is creating a well-functioning market for the secondary material. We realised that one of the obstacles is the lack of carbon harmonisation of the by-products creating an end of waste right here. So, the *Circular Economy Action Plan* puts as a goal...to harmonise [and create] easier symbiotic exchange between the member states."

Making the case

Daniella Chalakova from Aurubis, Germany, presented the case for industrial symbiosis with the example of iron silicate, a by-product of copper production.

She explained that "using this...manufactured mineral actively contributes to the circular economy and increases resource efficiency, by conserving scarce natural minerals such as gravel, sand and mineral flour, and also preventing it from going to waste into landfill."

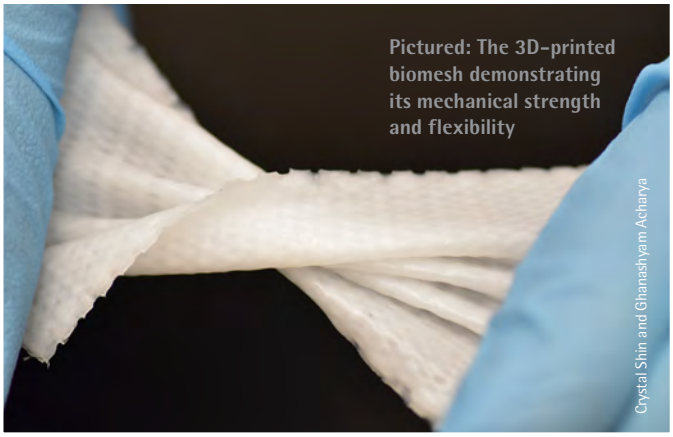
Chalakova noted that iron silicate can be used in a variety of sectors, including construction as a filler or aggregate in the concrete mixture, as aggregates for the base layer in road construction, or for clinker and cement.

She acknowledged policy developments that could encourage industrial symbiosis, including a minimum recycled content quota and mandatory preference for secondary mineral aggregates.

Finally, she explained that policy needs to stimulate sector integration and a market for engineered minerals, and reward synergies in the transition towards a climate neutral and more circular economy.

Inhibiting inflammation post hernia repairs

by Andrea Gaini



Pictured: The 3D-printed biomesh demonstrating its mechanical strength and flexibility

Crystal Shin and Ghanashyam Acharya

A 3D-printed biomesh made with a phosphate crosslinked polyvinly alcohol (X-PVA) could be the answer to preventing complications following hernia repairs.

The non-absorbable mesh can be surgically implanted and sutured to repair soft tissue defects and injuries.

In a study from the Baylor College of Medicine, USA, researchers have found that the biomesh is pliable yet mechanically robust and acts as an inflammation trap by capturing pro-inflammatory cytokines. It can also modulate inflammation and minimise visceral adhesion formations.

"We designed the biomesh to yield an elastic modulus that closely matches with that of the abdominal muscles where it will be implanted during the hernia repair," says Dr Crystal Shin, Assistant Professor of Surgery at Baylor. "Matching elastic modulus improves its compliance. The biomesh can provide adequate mechanical strength and withstand abdominal pressure."

Shin notes that the approach to developing the biomesh is quite different to currently available surgical meshes. "For example, PROLENE, a commonly used prosthetic mesh is made with polypropylene. This mesh when implanted can induce foreign body reaction and inflammation, which can lead to adverse complications such as visceral adhesion, hardening and shrinking of the mesh over time, often requiring additional surgical interventions."

She explains that chemical modification of the new biomesh gives a negative surface charge. This inherent property means it can "capture" excess pro-inflammatory cytokines that are positively charged. This inflammation-modulation reduces visceral adhesions, improving recovery.

"We used a crosslinker, sodium trimetaphosphate (STMP) to improve the stability of PVA and to yield a negative surface charge (due to the phosphate crosslinking)," she explains. "STMP is a non-toxic crosslinker commonly used to crosslink polysaccharides in the food industry. This PVA and STMP solution was used to 3D print the biomesh."

In initial trials "we observed no visceral adhesion after two and four weeks of the biomesh implantation [in animal models]...We also observed the significantly lower expression of pro-inflammatory cytokines in the biomesh-implanted tissues. This demonstrated that the inflammation-modulating biomesh prevented visceral adhesion formation." The next step is to evaluate long-term efficacy.

Bio-inspired surgical suture

A lotus-fibre-mimetic spiral structure made from bacterial cellulose (BC) hydrogel fibre is demonstrating suitability for surgical sutures, researchers report, with high strength and toughness, biocompatibility, stretchability, and high-energy dissipation.

Compared with commercial surgical sutures with higher modulus, the biomimetic hydrogel fibre (BHF) has similar modulus and strength to soft tissue, like skin. The stretchability and energy dissipation allows it to absorb energy from the tissue deformation around a wound and protect it from rupture.

Yu Shuhong, from the University of Science and Technology of China, explains that unlike polymer-based hydrogels, the BHF is based on the BC with 3D cellulose nanofibre networks produced by bacteria. The fibres provide a reversible hydrogen bonding network that is believed to cause these mechanical properties.

The researchers have applied a constant tangential force to the pre-treated BC hydrogel along the cross-sectional direction. Then, its two sides are subjected to opposite tangential forces and local plastic deformation occurs.

The hydrogen bonds are broken by the tangential force, causing the hydrogel strip to twist spirally and the network to slip and deform. When the tangential force is removed, the hydrogen bonds reform between the fibres and the spiral structure is fixed.

Planting the seed for real-time arsenic monitoring in soil

by Andrea Gaini

A nano-bionic optical sensor embedded in plants is detecting and monitoring, in real time, levels of arsenic in soil.

"[The technology] is a living plant-based sensor device that is created by integrating nanoparticle sensors within plant tissues without detrimental effect," explains Dr Tedrick Thomas Salim Lew, Scientist at Institute of Materials Research and Engineering, Singapore.

Developed as part of the research group at the Singapore-MIT Alliance for research and Technology (SMART), the sensor is built using single-walled carbon nanotubes that are wrapped in specific DNA sequences to selectively recognise arsenic molecules. The nanotubes are about 5nm in diameter and 400-800nm in length. When arsenic molecules encounter the nanoparticles, their fluorescence intensity changes and portable electronics are able to pick up the variation.

"The plant becomes a sensor while still being alive, hence turning them into self-powered detectors," Lew explains.

"The nanoparticle sensor can access the internal information within the plants in their natural state and translate this information into an optical signal that can be intercepted by smartphone or portable devices," he says.

Arsenic – the highly toxic, heavy metal chemical element – can appear in natural water supplies, often where land is less expensive and used for farming, and can cause serious health issues when ingested in quantities above 10 parts per billion (ppb). Staple crops such as rice accumulate arsenic, creating a potential hazard for humans.

Previously, conventional methods of measuring arsenic levels included regular field sampling, plant tissue digestion, extraction and analysis using mass spectrometry. The new approach couples nanoparticle sensors with the plant's natural ability to efficiently extract analytes via the roots and transport them. It can detect as low as 0.2 ppb of arsenic in the soil, while the device can also monitor concentrations below the ground.

Besides detecting arsenic in rice and spinach, the team also used a species of fern, *Pteris cretica*, which can hyperaccumulate arsenic.

"As a laboratory tool, our sensor technology can help plant biologists breed rice plants that can resist arsenic. As a technology for the field, the sensors can form the basis for monitoring water supplies to remediate or address the problem of contaminated water," Lew says.

"The nanoparticle sensor we created is small and can be engineered to target specific subcellular compartments within plant tissues and cells. The combination of nanoparticle sensor and living plants results in the most sensitive arsenic sensor to date which is readable by a smartphone without the need for frequent soil or plant sampling."

Regarding the future of this technology, collaborator on the work, Professor Michael Strano at DiSTAP, says that single-walled carbon nanotubes have already been produced on a large scale, which makes their product scalable.

He concludes, "We are now working with the Singapore Government and other stakeholders to translate this technology to potential users in various fields and continuing the important research alongside local collaborators in Singapore, such as the Temasek Life Sciences Laboratory (TLL), to further optimise and enable urban farming through precision agriculture technology."

Nature's capacity to absorb carbon emissions in decline

A lack of nutrients and water for plants is limiting the greening of Earth and causing CO_2 levels in the atmosphere to rise rapidly, according to a joint study by researchers in Spain and China.

The role of vegetation in mitigating climate change is key because it reduces the excess carbon that we humans emit into the atmosphere, called the fertilising effect of CO_2.

According to the study, co-directed at the Centre de Recerca Ecològica i Aplicacions Forestals (CREAF) in Barcelona and at the University of Nanjing, there has been a reduction in the fertilising effect of CO_2 of 50% progressively since 1982 due to two main factors – the availability of water and nutrients.

"There is no mystery about the formula, plants need CO_2, water and nutrients in order to grow. However much the CO_2 increases, if the nutrients and water do not increase in parallel, the plants will not be able to take advantage of the increase in this gas", explains Professor Josep Peñuelas at CREAF.

He warns, "These unprecedented results indicate that the absorption of carbon by vegetation is beginning to become saturated. This has very important climate implications that must be considered in possible climate change mitigation strategies and policies at the global level. Nature's capacity to sequester carbon is decreasing and with it society's dependence on future strategies to curb greenhouse gas emissions is increasing."

From seawater to lithium

By Andrea Gaini

A technique to extract high-purity lithium from seawater is being put forward by researchers at King Abdullah University of Science and Technology (KAUST), Saudi Arabia.

The team is deploying an electrochemical cell containing a ceramic membrane made from lithium lanthanum titanium oxide (LLTO), which contains holes just wide enough to let lithium ions pass through while blocking larger metal ions.

The cell contains three compartments. Seawater flows into a central feed chamber, where positive lithium ions pass through the LLTO membrane into a side compartment that contains a buffer solution and a copper cathode coated with platinum and ruthenium. Meanwhile, negative ions exit the feed chamber through a standard anion exchange membrane, passing into a third compartment containing a sodium chloride solution and a platinum-ruthenium anode. The lithium-enriched water then becomes the feedstock for further processing cycles. After the process is complete, the water is released back into the sea.

Zhiping Lai, Researcher at KAUST, claims that compared to conventional evaporation and precipitation, the membrane process will be much more energy-efficient, faster, and with a smaller footprint. "Our method can extract lithium from resources with extremely low lithium concentration and high magnesium/lithium ratio.

"LLTO has been developed for more than 40 years. It is well-known in the battery research field as one of the excellent solid electrolytes because of its high lithium conductivity, but less known in the membrane research field...The high conductivity combining the high selectivity is the key property for the success of our process," Lai says. This method has been tested using Red Sea seawater and is said to have enriched lithium from 0.21ppm to ~9,000ppm.

"The process consumed about 76.34kWh electricity per 1kg lithium extraction. At the same [time], 0.87kg H_2 and 31.12kg Cl_2 were produced as by-products. The value of these products can well offset the electricity cost," suggests Lai.

Adjusting the pH solution delivers solid lithium phosphate with mere traces of other metal ions. The team claims this is pure enough to meet manufacturers' requirements.

Lai explains that "the membrane industry has now accumulated enough knowledge and experience to scale up [such] a membrane process to large industrial scales. A notable example is the reverse osmosis process to produce fresh water from seawater."

Moving forward, the team seeks to develop an efficient membrane preparation method to fabricate it at scale at a low cost. They will also test it in different lithium source conditions, studying the long-term stability and further optimise the structure and cell design to improve efficiency.

"We also plan to explore the potential integration of renewable energy and seawater desalination to improve the process viability," Lai adds.

Regarding the environmental impact, Lai suggests that the process "is environmentally benign" as it does not generate a concentrated brine, as in the case of seawater desalination, and no chemicals are added or produced. He believes as lithium is not an essential element in living systems, its removal will not affect the ocean's ecosystem.

He continues, "Our [approach] will also help other processes to be environmentally friendly. Seawater desalination generates a large amount of concentration brine, which is typically discharged back to the sea because it is economically unfeasible to recover it.

"Since the publication of our work, we have been contacted by many seawater desalination plants for collaboration because now they see they can extract lithium from the concentrated brine and generate more value, [which] may [make zero discharge more] affordable."

Spilling the fluids about diamond's history

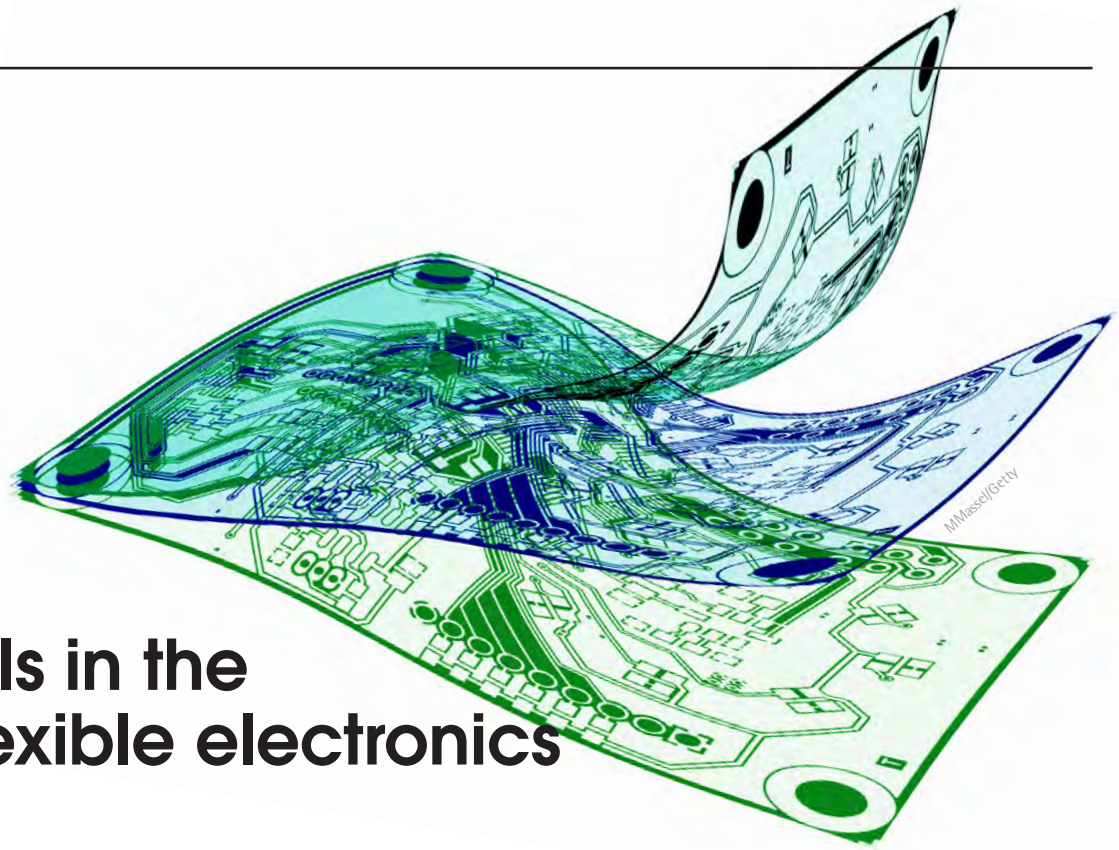
Analysing tiny pockets of liquid could help scientists learn more about the age of diamond formations.

Researchers from Columbia University, USA, have dated the fluids by measuring traces of radioactive thorium and uranium, and their ratios to helium-4 – a rare isotope that results from their decay. They have also uncovered the maximum rate at which helium molecules can leak out of the diamond – without which, conclusions about age, based on the abundance of the isotope could be thrown off.

The team has identified three distinct periods of diamond formation within separate rock masses that eventually coalesced into present-day Africa. They have also found at least one diamond-encapsulated fluid from both the oldest and youngest eras, showing that new layers can be added to old crystals over vast periods of time.

Pictured: Trials were conducted using seawater from the Red Sea

DariaZ/Getty



Solar cells in the fold of flexible electronics

by Andrea Gaini

Single-walled carbon nanotube (SWNT) films could be the answer to foldable solar panels in indoor, light-harvesting, flexible electronics, suggest scientists in South Korea, thanks to their high transparency and mechanical resilience. They claim to have achieved the highest power conversion efficiency of 15.2% in solar cells using SWNTs.

The team has embedded carbon nanotubes directly into polyimide (PI) during high-temperature curing. Inserted molybdenum oxide thermally dopes the SWNTs to enhance conductivity and transparency of the entire film. Researchers have then demonstrated its device applicability by applying it to perovskite solar cells.

By introducing small impurities – withdrawn electrons to molybdenum oxide – into the SWNT-PI nanocomposite layer, the energy needed for the electrons to move across the structure is much smaller, and more charge is generated for a given amount of current.

The resulting prototype is said to have "far exceeded" expectation. Only seven micrometres thick, the composite film exhibits resistance to bending, almost 80% transparency, with strong power conversion efficiency.

Dr Il Jeon of Pusan National University, says, "Having a foldable transparent conductor is the key to achieving foldable solar panels. This study paves the way for future, highly efficient, foldable electronics technology for our everyday lives."

He adds, "Despite the word 'solar', future technology of solar cells are inching towards indoor light-harvesting wearable devices. This cannot be realised without highly conductive and mechanically flexible (foldable) transparent conductors. We can expect our new transparent conductors not only in solar cell applications but in many optoelectronic devices."

The device has undergone a folding cycle test with a radius of less than 0.5mm. "Stability tests showed that the solar cells made with SWNT-embedded conductors could withstand over 10,000 folding cycles, unlike those using conventional conductors, for example, indium-tin oxide or carbon electrodes simply laminated on a substrate," Jeon explains. "The only foldable transparent conductor technology that stacks up to ours is PEDOT:PSS. However, PEDOT:PSS has drawbacks in chemical instability.

"By embedding the carbon nanotubes in the polymer instead of simply depositing them, they achieved smooth morphology, excellent electrical resistance and unprecedented thinness in the solar cells."

Jeon says that the research team is now looking to develop a stretchable device by modifying the PI composition.

Architecting a boost in solar efficiency

Constructing thin layers of specifically arranged nanoblocks could increase solar cell efficiency by a factor of five.

Physicists from the Martin Luther University Halle-Wittenberg (MLU), USA, are introducing a cell architecture – so-called nanocomposite – through stacked single layers of a typical material only a few nanometres in thickness on top of one another and offset them with nickel oxide strips running perpendicularly.

"The strips act as a fast lane for the electrons that are generated when sunlight is converted into electricity and which are meant to reach the electrode in the solar cell," says Dr Akash Bhatnagar, a Physicist from MLU.

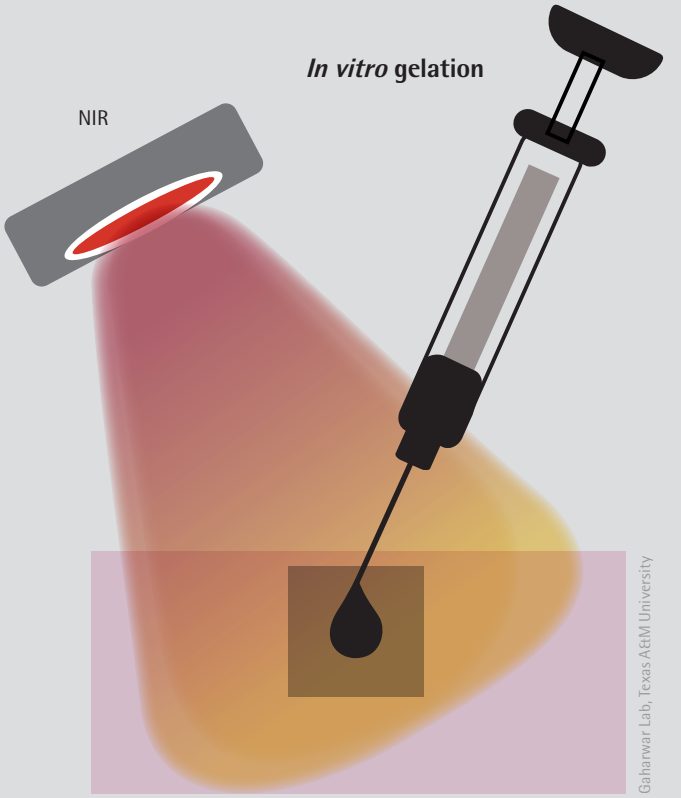
He explains, "Based on the properties of silicon it's not feasible to say that their efficiency can be increased indefinitely." His research team is therefore studying the so-called anomalous photovoltaic effect which occurs in certain materials.

They suggest that the anomalous photovoltaic effect does not require a p-n junction which otherwise enables the flow of current in silicon solar cells. The direction of the current is determined at the atomic level by the asymmetric crystal structure of the corresponding materials. These materials are usually oxides, which are easier to manufacture and more durable. However, they often do not absorb much sunlight and have a very high electrical resistance.

"In order to utilise these materials and their effect, creative cell architectures are needed that reinforce the advantages and compensate for the disadvantages," explains Lutz Mühlenbein, lead author of the study.

Biomedical hydrogels optimised with near-infrared light

By Andrea Gaini



Above: Gelation of hydrogels loaded with 2D molybdenum disulphide (MoS_2) nanoassemblies upon near-infrared exposure

Researchers in the US are developing hydrogels from nanomaterials that can be manipulated with near-infrared light (NIR). In doing so, they hope to better control such materials for optimal use in tissue regeneration or drug delivery.

A team at Texas A&M University explain light-responsive hydrogels are an emerging class of materials used for non-invasive, non-contact medical devices in areas such as photothermal therapy, photodynamic therapy, drug delivery and regenerative medicine. However, they note that current light sources, such as UV light and visible light, cannot sufficiently penetrate the tissue to interact with the hydrogel.

Instead, the scientists are taking advantage of the NIR absorption capabilities of a new class of 2D nanomaterials – molybdenum disulphide (MoS_2) – combined with certain polymers to form hydrogels.

The method has been tested both *in vitro* and *in vivo*. The results reveal that the hydrogel can be formed by NIR light inside the tissue beneath the skin.

"Traditionally, UV light is the major light source to trigger hydrogel gelation. NIR light has a higher penetration depth for skin and is more biocompatible…Therefore, this material has a great advantage," says Hung Pang Lee, graduate student at the University.

"These nanosheets with high photothermal conversion efficiency can absorb and convert NIR light to heat…The photothermal effect can heat up the surrounding environment to cause the phase transition of the thermo-responsive polymer for forming crosslinks."

While the current methods of gelation heavily rely on the use of photo-initiators or thermo-initiators to trigger hydrogel formation, using NIR light without photo-initiators is an attractive light source for *in situ* gelation, Lee explains.

The NIR light could enable therapeutic hydrogels to form in the body for precise drug delivery, for example, cancer therapies may be retained within the tumour to ease the side effects. The technique could also generate heat inside the tumours to ablate cancer cells through photothermal therapy, which can be combined with chemotherapy.

Lee concludes, "For now, the materials can be facilely synthesised in research scale. We want to investigate if there are more types of nanoparticles that can be used."

A nose for cancer detection

An odour-based test that sniffs out vapours emanating from blood samples could help distinguish between benign or malignant pancreatic and ovarian cells with up to 95% accuracy, according to a new study from the University of Pennsylvania, USA.

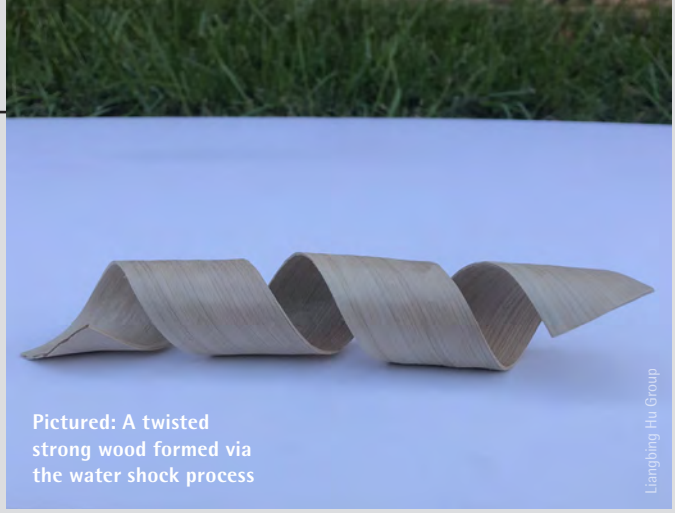
The electronic olfaction – e-nose – system is equipped with nanosensors calibrated to detect the composition of volatile organic compounds (VOCs) emanating from blood plasma samples.

The tool uses artificial intelligence and machine learning to decipher the mixture of VOCs. The researchers suggest it could be used as a non-invasive approach to screen for harder-to-detect cancers.

Charlie Johnson, Professor at the University, says, "The data shows we can identify these tumours at both advanced and the earliest stages, which is exciting. If developed appropriately for the clinical setting, this could potentially be a test that's done on a standard blood draw that may be part of your annual physical."

Taking shape – an inherently mouldable wood

By Andrea Gaini



Pictured: A twisted strong wood formed via the water shock process

Liangbing Hu Group

Scientists claim to have developed a wood with a unique wrinkled cell structure that renders the material foldable and mouldable while also improving its mechanical strength.

The technique, known as 'water-shock' assisted cell wall engineering, could help shape wood into lightweight and strong 3D structures that are processed in a similar manner to polymers and metals. This could open up possible applications in buildings, automotives and aircraft, where both complex shapes and strong mechanical properties are required.

Dr Liangbing Hu, from the University of Maryland, USA, explains, "The natural wood starting material has a 3D hierarchically porous cellular structure with many hollow vessels and fibres. Cell wall engineering approach involves partially delignifying and softening natural wood."

The paper, *Lightweight, strong, moldable wood via cell wall engineering as a sustainable structural material*, published in *Science*, explains the process. "Firstly, a sheet of natural wood (basswood) was partially delignified by treating with a boiling aqueous solution of 2.5M sodium hydroxide and...sodium sulphite for 48 hours, followed by immersion in water several times to remove the chemicals.

"Next, this partially delignified wood (~300wt.% water content) was air dried at room temperature (25±4°C) and a relative humidity of 45-60% for 30 hours to form the shrunken wood intermediate (~8-12wt.% water content), which was then immersed in water for three minutes (water-shock process) to form the mouldable wood.

"Finally, the 3D-moulded wood was achieved by shaping the mouldable wood into the desired structure and removing water from the material by air drying at room temperature for 30 hours."

Hu suggests that the selective opening of the cell wall structure may provide two simultaneous effects. The partially open vessels create space that can accommodate both compressive and tensile deformation in an "accordion-like" manner, allowing the material to undergo severe compression and tension while being folded, even up to 180° without cracking.

Meanwhile, the densely packed closed fibres can provide mechanical support for enhanced strength.

The different shapes and structures that can be achieved can then be set into place with air drying to remove the remaining water, forming the final 3D-moulded wood product by mechanical bending, folding, twisting and moulding press.

Hu believes this improves on current techniques of wood manipulation, which rely on physical sculpting, carving or turning into complex 3D shapes, but do not change the intrinsic material. Furthermore, he notes that conventional wood shaping techniques can only achieve large curvature i.e., the wood can only be slightly bended.

He says, "Our work describes an...approach to endowing wood with many of the advantages of metals and plastics (strength and formability)...Given that wood is one of the oldest structural materials, this development represents a significant advance for wood's structural applications with potentially transformative utility of this renewable material."

As a proof-of-concept, the team has shaped the mouldable wood into a honeycomb core structure that can potentially replace aluminium alloy in construction.

Hu adds, "In addition to metal replacement, the 3D-moulded wood can also replace traditional wood with much better performance, with a selection of a broad range of wood species as the starting materials. For example, 3D-moulded wood veneer fabricated from fast growth wood can be a cost-effective, high-performance skin layer for advanced furniture with significantly improved mechanical properties (i.e., scratch resistance)."

He suggests that scaling the manufacturing of corrugated 3D-moulded wood structures could be accomplished using the mature roll-to-roll manufacturing processes from the wood and pulp industries.

Wood that cuts like a knife

Researchers are creating wooden knives that they claim are nearly three times sharper than stainless-steel dinner table knives and 23 times harder than normal wood.

"Even though it's often used in building, wood's strength falls short of that of cellulose, because wood is made up of only 40-50% cellulose, with the rest consisting of hemicellulose and lignin, which acts as a binder," says Teng Li, a Materials Scientist at the University of Maryland, USA, who worked on the project.

Li and his team sought to remove the weaker components without destroying the cellulose skeleton. "It's a two-step process," says Li. "In the first step, we partially delignify wood. Typically, wood is very rigid, but after removal of the lignin, it becomes soft, flexible, and somewhat squishy. In the second step, we do a hot press by applying pressure and heat to the chemically processed wood to densify and remove the water."

After the material is processed and carved into the desired shape, it is coated in mineral oil to reduce water absorption and extend the knife's lifetime.

Remanufacture of dies for metal production

By Andrea Gaini

A low-cost remanufacturing solution could extend the life of dies to shape metal during production by 120%, helping UK manufacturers to embrace the circular economy, boost sustainability and save costs, say researchers.

The process has been developed by the National Manufacturing Institute Scotland (NMIS), UK, which is operated by the University of Strathclyde and is part of the High Value Manufacturing Catapult. Project partners include Toolroom Technology Limited, Applied Tech Systems, Hybrid Manufacturing Technologies, INSPHERE Ltd and Kimber Mills International.

The two-year £1.2mln project, called DigiTool, is part funded by Innovate UK and focuses on the remanufacture of dies, which are commonly used across the hot forging, stamp and press, moulding, and oil and gas industries to shape metal during production, but are typically subject to high costs and long manufacturing lead times.

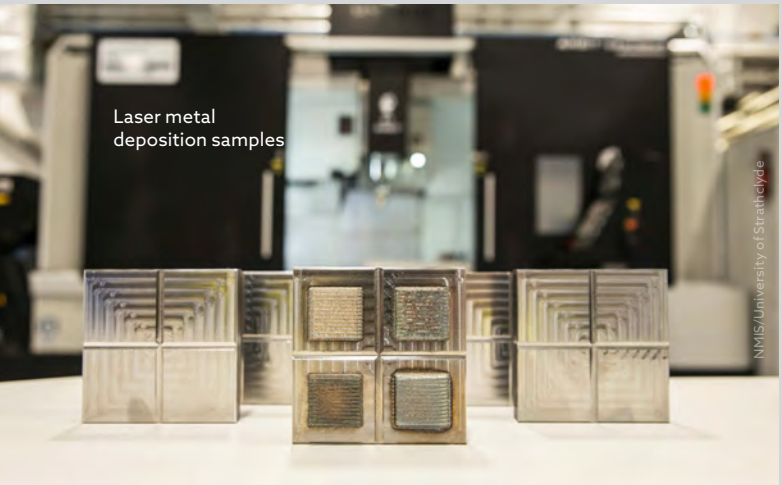
The framework incorporates a three-stage process using a hybrid platform that combines additive manufacturing and machining and can be retrofitted to a legacy machine tool.

"The idea was to use laser metal deposition with powder (LMD-p) technology to repair worn forging dies," says Stephen Fitzpatrick, Machining and Additive Manufacturing Team Lead at NMIS.

Fitzpatrick explains that die repair is normally achieved by welding and requires large-scale equipment. While this process is also detrimental to die substrate, LMD-p uses blown powder with a laser melt pool that is shallow compared to welding, so has a lower impact on die substrate.

Fitzpatrick explains, "We retrofit a three-axis computer numerical control (CNC) milling machine with LMD-p hardware to allow removal of worn areas of dies, deposit hard-facing alloy in cut areas and machine to final geometry.

"In terms of the material used, we selected likely candidate materials available for LMD-p which would give hard wearing, machinable surfaces. The die material was H13 tool steel, and the cladding (repair material) was Metcoclad 21."


Laser metal deposition samples

NMIS/University of Strathclyde

He continues, "[At] stage one, we scan the die for wear – the laser scanner finds areas deviating from the original design condition. [At stage two], we then machine the worn die areas in preparation for LMD-p deposition. Finally, LMD-p hard facing cobalt alloy (Metcoclad 21) is used to fill worn areas with sufficient material, allowing for CNC machining to achieve the desired final geometry."

To test the method, repaired dies have been used in a production run with a forging partner. The results show that die life exceeds the original H13 tool steel die, producing more parts by 108%.

The retrofitted hybrid system at NMIS is also said to demonstrate:

- Reduction in material wastage during re/manufacturing or repair.
- Lower lead times to replace worn parts.
- Significant reduction in energy consumption due to the hybrid nature of the process.
- Promising circular economy approach.
- Improved tool life enhancing functional material performance.

The researchers report that the technique is already in use in production environments to repair metallic components, and is ideal for small-scale intricate geometry repairs with a large selections of alloys available. The laser head can be installed on large-scale CNC as required, allowing for a low-cost retrofit.

Lead-absorbing tape for solar power

A cost-effective Scotch-tape-like film that can be applied to perovskite solar cells (PSCs) is said to capture 99.9% of leaked lead in the event of solar cell damage. It could speed up commercialisation of PSCs for use in solar panels.

Researchers at Northern Illinois University and the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) in Golden, Colorado, say the film is industry ready and would help alleviate health and safety concerns without compromising performance or operation.

The transparent tapes use lead absorbents made with a standard solar ethylene vinyl acetate (EVA) film and a pre-laminated layer of lead-absorbing material. The tape can be attached to both sides of fabricated PSCs in the standard encapsulation process used in silicon-based solar cells.

Among the tests used to assess the durability of the new technology, the scientists have exposed the film-encapsulated PSCs to outdoor, rooftop conditions for three months. Razor blades and hammers were used to damage the solar cells before they were submerged in water for seven days. The tapes exhibited a lead-sequestration efficiency of over 99.9%.

Small amounts of water-soluble lead continue to be essential components of the light-absorbing layer of high efficiency PSCs, which must be able to withstand severe weather for commercial viability.

Optical sensor mimics human eye

by Andrea Gaini

Selman Keles/Getty

A retinomorphic optical sensor that mimics the human eye's ability to capture changes in the visual field is the focus of research at Oregon State University (OSU), USA.

The device could be used in real-time processing of visual information in autonomous vehicles and robotics, or for projectile tracking.

The sensor uses ultra-thin layers of perovskite semiconductors – a material that has been widely studied for its solar energy potential. The semiconductors can change from strong electrical insulators to strong conductors when placed in light.

"Most conventional detectors operate by outputting a signal (e.g., a voltage) which is roughly proportional to the intensity of the light that falls upon it," says Assistant Professor John Labram, one of the researchers working on the project at OSU College of Engineering.

"Our device operates on a different principle. It will only output a high voltage if the intensity of light is changing, regardless of intensity level. For example, if a light is switched on and left on over the detector, it will output a brief voltage spike followed by a quick decay back to zero volts. If the sensor is under a bright but constant light, it will output zero volts regardless of the light intensity."

In the same way, Labram explains that the human sense of vision is particularly well adapted to detect moving objects and is comparatively "less interested" in static images. "The way the eye processes optical information is incredibly complex, but cells are known to respond more strongly to optical signals that have strong time-dependence than those that are static," he says.

"This is because much of the field of vision is not relevant for mammalian behaviour. For example, mammals will, in general, respond much more strongly to objects travelling towards them than to a static background image."

The sensor stems from the same motivation and is said to be the first such device that works fundamentally like photoreceptors in the eye. The researchers note that it is one part of an ongoing endeavour to make certain types of electronics more human-like.

By using the perovskite semiconductors, the team has developed an optical circuitry that gives priority to signals from photoreceptors detecting a change in light intensity, similar to the human eye.

Although Labram's lab can currently test only one sensor at a time, his team has measured a number of devices and created a numerical model to replicate their behaviour. This has enabled them to simulate an array of retinomorphic sensors to predict how a retinomorphic video camera would respond to input stimulus.

A simulation using footage of a baseball practice session demonstrates the expected results. Players in the infield show up as clearly visible, bright moving objects. Relatively static objects — the baseball diamond, the stands, even the outfielders — fade into darkness.

"Conventional sensing technologies, like the chips found in digital cameras and smartphones, are better suited to sequential processing," Labram continues. "Images are scanned across a 2D array of sensors, pixel-by-pixel, at a set frequency. Each sensor generates a signal with an amplitude that varies directly with the intensity of the light it receives, meaning a static image will result in a constant output voltage from the sensor."

The ability to easily differentiate moving objects from the background in a visual field is valuable in a range of applications. Labram adds, "You could summarise [our study] as a single pixel doing something that would currently require a microprocessor."

The new sensor is said to be suitable for the neuromorphic computers that will power the next generation of artificial intelligence in applications such as self-driving cars, robotics and advanced image recognition. Unlike traditional computers, which process information sequentially as a series of instructions, neuromorphic computers are designed to emulate the human brain's parallel networks.

"People have tried to replicate this in hardware and have been reasonably successful," Labram says. "However, even though the algorithms and architecture designed to process information are becoming more and more like a human brain, the information these systems receive is still decidedly designed for traditional computers."

So, to reach its full potential, a computer that "thinks" more like a human brain needs an image sensor that "sees" more like a human eye.

Dandelion-inspired man-made flyers receive funding boost

The European Research Council (ERC) has awarded a €2mln grant to a project looking to reproduce the flight capabilities of the dandelion.

Dr Ignazio Maria Viola and Naomi Nakayama of the California Institute of Technology (Caltech), USA, have revealed that the dandelion's flight is enhanced by a flow feature that has never been observed before – the separated vortex ring.

In the project, Viola will seek to understand and establish proof-of-principle of a completely new fluid mechanism that might enable small man-made flyers to passively hover in turbulent wind.

The funding will enable construction of a one-of-its-kind wind tunnel to study small flyers in gusts.

Extracting metals from volcanoes

By Andrea Gaini

Above: White Island (Whakaari) volcano in New Zealand is an active volcano on the Pacific Ring of Fire that discharges 100t of copper and 4.5kg of gold in its volcanic gases, on average each year to the atmosphere

Valuable metals, such as copper, gold, zinc, silver and lithium, could be extracted from the lenses of hot hypersaline liquid trapped in porous rocks below dormant volcanoes.

Scientists from Oxford University, UK, believe the lenses, also known as brines, can be extracted to the surface via wells, using the heat of the fluids to generate geothermal power to drive the wellhead operations.

"The economic bounty of volcanoes remains one of the untapped frontiers in our drive to net-zero," says Professor Jon Blundy at the University.

"Several volcanoes worldwide pump tonnes per day of copper out into the atmosphere in the form of hot gases and aerosols. It is not practical to capture these emissions, but it makes the point that volcanoes, by their very nature, are hot and metal-rich.

"Almost all non-ferrous metals derive ultimately from volcanic processes. Normally, we have to wait for the products of hydrothermal ore formation to cool and be exhumed to the surface. Brine-mining short circuits this process by tapping into the hot mineralising liquor. This can have huge environmental benefits," he explains.

Bundy says that the lenses can be imaged geophysically as electrical conductivity anomalies and have been seen beneath most active or dormant volcanoes.

"The lenses typically have dimensions to 2-3km radius and 1-2km thickness. The total possible copper endowment of these lenses is over 1.5Mt. It could be quite a bit more depending on the porosity of the rock in which the brine is stored, and [its] temperature. Hotter brines (>450°C) can dissolve more metals."

The concept came from the scientists' work on volcanoes and the formation of giant copper deposits. They have used a combination of hydrodynamic simulations to model the formation and evolution of brine lenses, as well as high temperature and pressure experiments to determine the solubility of metals in these brines.

"We…studied drill core from depths of 1.5-3km at several geothermal or volcano sites to determine the compositions of brines as trapped as tiny 'fluid inclusions' in crystals." The researchers are looking into drilling a test bore hole to sample fluids directly.

"Although this would not be a working mine in the first instance, it would enable us to better constrain the porosity and permeability of the rocks at the reservoir depths, and this ultimately will determine the fluid productivity. It would also enable us to test some different materials and extraction technologies," says Bundy.

"There are several materials challenges. The first is to design coatings for well-bore casings that are corrosion resistant to hot brines. Using titanium casings is prohibitively expensive, so ceramic coatings on steel alloys may be the best approach here."

He adds, "We also need to develop strategies to ensure that the solute load reaches the surface, rather than scaling the well lining up which it travels. This is a common problem in geothermal energy. However, the problematic scales in such situations are, in fact, very high-grade ores."

So far, the only known case of directly tapping into hot brines was at the Kakkonda geothermal site in Japan in the 1990s, which recovered small volumes of metal-rich brines.

"However, these very quickly precipitated out their metals due to the pressure and temperature drop during sampling. This is a challenge for 'brine mining' as envisaged, but one that can be addressed," asserts Bundy.

The proposed method has yet to be tested, but he says that most of the de-risking research is now complete.

Mining raw materials from thermal springs

Researchers from Karlsruhe Institute of Technology (KIT), Germany, are developing methods for extracting mineral resources directly in geothermal power plants in Chile.

In the BrineMine research project, scientists are seeking to extract energy and minerals, such as lithium, cesium and gold, as well as drinking water from thermal springs.

They have developed a process chain that uses heat from the geothermal brine for energy recovery and later pre-concentrates the cooled liquid, which has a relatively low concentration, by reverse osmosis, obtaining drinking water. The brine concentrate is then further concentrated by membrane distillation until it is saturated.

A demonstration plant has been set up in a geothermal power plant in the Upper Rhine Graben.

"The thermal energy required for the entire process can be covered directly from the excess heat of the power plant process," says Project Manager Dr Joachim Koschikowski at the Fraunhofer Institute for Solar Energy Systems, Germany.

ArtMarie/Getty

Face masks hit the road

By Andrea Gaini

Disposable face masks could be recycled to make roads, in a circular economy solution to pandemic-generated waste.

The new road-making material – developed with a mix of shredded single-use face masks and processed building rubble – meets civil engineering safety standards, according to researchers at RMIT University, Australia.

They suggest that 1km of a two-lane road could use up around three million masks, diverting 93t of waste from landfill.

"Our experimental results show that the mixture of shredded face masks and recycled concrete aggregate satisfies the stiffness and strength requirements for the base layers of roads," says Dr Mohammad Saberian, lead author of the research.

"We identified an optimal mixture that is 1% shredded face masks to 99% recycled concrete aggregate. This blend delivers on strength while maintaining good cohesion between the two materials."

Saberian explains that "the masks could provide higher strength and stiffness, and more flexibility to the base and sub-base of roads, as they play a reinforcing role in binding the rubble particles. The introduction of randomly distributed shredded face masks enhances the stretching resistance between aggregates.

"Consequently, the ductility, flexibility and strength of the rubble-mask, road-making mix increases. We can build better and stronger roads by the adoption of face masks in road layers".

Moreover, he notes, "too many masks are finding their way out of bins, being blown into gutters and washing down the drain, impacting our waterways and wildlife. The most severe effect is the fact that many masks are finding their ways to rivers and oceans, which is a threat to marine life and, consequently, human life".

In fact, Saberian says it has been reported that if the current trend of face mask generation continues, the number of masks in oceans could be higher than the number of fish.

The new construction material was tested through a series of laboratory experiments with different percentages of shredded face masks mixed with recycled concrete aggregate for road base and sub-base applications. These include tests for tensile strength, unconfined compression strength and resilient moduli.

While the experimental study initially has used a small amount of unused surgical face masks, other research is investigating effective methods for disinfecting and sterilising used masks.

A review of disinfection technologies is said to find 99.9% of viruses can be killed with the 'microwave method', where masks are sprayed with an antiseptic solution then microwaved for one minute.

And, in related work, RMIT researchers are also exploring the use of shredded disposable face masks as an aggregate material for making concrete, with "promising preliminary findings".

Saberian explains, "Given that most personal protective equipment (PPE) is mainly made of plastics, including polypropylene, polyvinyl chloride and nitrile butadiene rubber, the methodology proposed in this study can be applied to different PPE, such as safety clothing and gloves. However, a feasibility study, similar to one reported in our study, needs to be conducted to evaluate the potential use of other waste PPE as pavement base/sub-base materials."

Moving forward, they will be looking at "[bringing] this technology to a real-life road construction project by making a road prototype. Our team is now looking to partner with local governments or industry who are interested in collecting masks and building a road prototype. We are also conducting research on the application of face masks for concrete construction".

Cutting CO_2 emissions in cement substitute production

Hanson's Regen Ground Granulated Blastfurnace Slag (GGBS) plant in Port Talbot, Wales, UK, is trialling green hydrogen to replace some of the natural gas used to power the plant.

The initiative is part of a £9.2mln Reducing Industrial Carbon Emissions (RICE) project, funded by the European Regional Development Fund (ERDF), and is being run by Hanson UK, in collaboration with the Energy Safety Research Institute at Swansea University, UK.

Hanson's Port Talbot plant produces Regen GGBS, which is used as a replacement for up to 80% of the cement in concrete.

Long term, Iain Walpole, the Environmental Sustainability Manager at Hanson UK, explains that "being able to kick-start the hydrogen economy utilising cheaper sources of initial energy, such as industrial waste heat, will allow us to form a more valuable commodity for transport".


Polymateria

Pictured: A biodegradable and recyclable plastic created with the Polymateria technology

Twinning with a biodegradable and recyclable plastic film

by Andrea Gaini

A biotransformation technology that makes a polyethylene film biodegrade within a year also renders the material recyclable, claim scientists at Polymateria, a start-up based at Imperial College London, UK.

They say this is the first time such a film has been independently proven both recyclable and biodegradable in the natural environment. The recyclability testing has been conducted by the ISO-accredited Impact Solutions in the UK.

Polymateria has also developed a rigid plastic material for products such as disposable drinks cups, which also biodegrades and is in the final phases of testing for recyclability.

Explaining how the technology works, Steven Altmann-Richer, the company's Global Head of Public Affairs and Regulatory Strategy, says, "Packaging manufacturers can add the 'drop-in' Polymateria additive – which comes in pellet form – to their plastic resin during the manufacturing process. This additive is known in the industry as a masterbatch, and it contains chemicals (we call them catalysts and cocatalysts).

"After a period specified by the manufacturer, the dormancy…ends and the catalysts in the masterbatch break down the hard crystalline and amorphous structure into a wax-like substance through multiple chemical reactions, achieving carbon-carbon bond scission and ensuring no microplastics are created."

The proprietary use of 'synthetic' prebiotics attracts natural decay agents such as microbes, fungi and bacteria to fully consume the wax-like substance.

Recycling, however, can take place before biodegradation is triggered, with a 'recycle by' date alerting consumers and encouraging responsible disposal.

On a range of packaging – polyethylene and polypropylene – independent third-party laboratory testing shows 100% biodegradation on a rigid plastic container in 336 days and film material in 266 days in the open environment. The process is said to leave zero microplastics behind.

"Our product stewardship ensures we only work with pure materials capable of full and safe return to nature but also don't damage the waste hierarchy of reduce, reuse and recycle," Altmann-Richer adds.

"We've deployed the technology in polyolefins first as polyolefins are the type of plastic most commonly found in the natural environment. This is where we've focused all of our innovation efforts to date. We wanted to figure out how you could return polyolefins to nature, but equally make the solution time-controlled to give recycling every chance to happen." The film can be recycled and turned into products like flowerpots or pallets.

Polymateria's technology works with a wide range of product types such as clear plastic containers, bottles lids, supermarket bags, fruit nets, candy wrappers, cigarette film, face masks and more.

Altmann-Richer notes, "Polymateria has [also] supported the development of new standards for polymer analysis, eco-toxicity and biodegradability testing. We have worked alongside a diverse steering group of technical specialists, including those from Imperial College London, Avient and the UK Government, to help framework these standards, informed by Polymateria's own strict internal criteria.

"This has led to the development of a new British standard for biodegradable plastic. The new BSI PAS 9017 addresses a significant gap in the plastics landscape to ensure claims about biodegradability can be independently verified without causing any harm to the environment.

"The standard is a test specification with strict pass/fail criteria to measure the biodegradability of a polyolefin plastic in the open environment without creating microplastics or causing ecotoxicity issues… Any product deploying our technology must meet the strict criteria set out in the PAS 9017 standard to ensure no microplastics are created, no harmful substances are left behind and full biodegradation occurs."

Making mineral plastics

A 'mineral plastic', created from calcium carbonate nanoparticles linked using polyacrylic acid in water, can be recycled or transformed and is self-healing in its gel state, researchers find.

The group from the University of Konstanz and the University of Stuggart, Germany, claim to have created an entirely new plastic using the guiding principle of "green chemistry" inspired by mineralisation in nature.

Once the material has dried, it takes on the distinctive qualities of plastic, being both durable and pliable at the same time. This is said to make it a suitable replacement for conventional plastics in dry applications, for example, in electronic components.

It can be produced without energy input at room temperature and is malleable and self-healing, says the team behind it. Cracks, for example, will close again after applying a drop of water. Two separate components can be joined together in the same way.

The gel can also be used as a temperature sensor, as it changes its colour when heated and it can be re-shaped without energy input. By adding water and a weak acid, such as acetic acid or citric acid, the gel will dissolve leaving the residual non-toxic polyacrylic acid.

"The production process of the hydrogel can directly be adapted by the industry, especially since the source materials are industrially produced at low cost," says Helmut Cölfen, Professor of Physical Chemistry at the University of Konstanz.

Engineering bacteria to extract rare earths

By Andrea Gaini

Scientists from Cornell University, USA, are engineering bacteria to extract rare earth elements (REE) – a process that they believe could replace the thermochemical methods currently in use.

The researchers have screened bacteria *Gluconobacter oxydans*, and identified a comprehensive set of genes that underly its bioleaching capabilities.

They explain that the bacteria is known for making an acid called biolixiviant that dissolves rock – it uses the acid to pull phosphates from REEs.

Postdoctoral Researcher, Alexa Schmitz, says, "*Gluconobacter* is an acetic acid bacteria capable of producing strong organic acids from sugars. In particular, it can rapidly convert glucose into gluconic acid and other similar compounds that we can then use for the extraction process. These organic acids break down quickly in the environment and are less harmful to biological life."

The aim of this work has been to manipulate the bacteria's genes so it extracts the elements more efficiently. To do so, they have used a method called 'Knockout Sudoku', that allows them to disable the 2,733 genes in the bacteria's genome one-by-one.

"Although we have excellent tools to read and write genomes, only a small percentage of gene functions are known. One of the best ways to elucidate a gene's function is to disable the gene and test for a change in function," Schmitz says. "We found several genes whose deletion resulted in an increase in bioleaching capability (up to 18%)."

He shares, "In our case, we've created a collection of strains, each with a different gene disabled. We then screened these knockout strains and found over 300 with differential abilities to use glucose to lower the media pH – a good predictor of bio-mining efficiency. Among this set, we selected the strongest and weakest acidifiers to confirm a direct effect on bio-mining."

Schmitz has identified genes that put the brakes on acidification and another that accelerates it.

Below: Cultures of different strains of *Gluconobacter oxydans* generating acidic biolixiviant that was used for bioleaching

Recovering rare earths from fertilisers

Engineered peptides are being put through their paces to identify and retrieve rare earth elements (REEs) from phosphogypsum, a by-product of fertiliser production.

Researchers from Penn State University, Case Western Reserve University and Clemson University, USA, are using a specialised membrane to separate out the REEs.

"Individual REEs have similar sizes and identical formal charges, so traditional membrane separation mechanisms are insufficient," says Lauren Greenlee, Associate Professor of Chemical Engineering at Penn State.

"A key technical goal of this research is to discover the mechanisms that underpin peptide-ion selectivity and leverage those mechanisms to design a new class of highly selective membranes."

"For our project, the hypothesis is that water molecules associated with the peptides binding to the REEs reorganise, and we can precisely control that reorganisation to be more efficient based on the individual REE."

Greenlee says that her team will examine the interactions at the atomic level, using X-ray absorption spectroscopy to validate how the molecules exchange atoms as they bind. "With modelling and experimentation, we'll continue to iterate to ensure we understand how the molecules work together."

The researchers are working to regulate the gene that accelerates acid production, hoping to create a system whereby the bacteria can run on affordable cellulose-derived sugars for energy.

The team has used mass spectrometry techniques to measure concentrations of REEs in solutions where mutants were exposed to ore and found that for some of these mutants the concentration is high.

"We tested REE extraction by mixing the biolixiviant produced by the bacteria with retorted phosphor powder... We incubated them with shaking for three days, removed any remaining solids, and then measured the concentration of all REE in the leachate using inductively coupled plasma mass spectrometry (ICP-MS)," Schmitz adds.

"We were very excited to find that the knockout strains with improved acidification also demonstrated improved bio-mining efficiency, as much as 18%.

"In particular, a few of the better bio-mining strains were disrupted in genes involved in the phosphate-specific transport (Pst) system. One of the primary reasons microorganisms generate organic acids is for the solubilisation of phosphate and other minerals in their environment.

"The Pst system is critical for sensing phosphate. We believe that the lack of these genes means the bacteria cannot sense that they have enough phosphate, and as a result they produce more organic acids."

Waste not – from mining scraps to hydrogen fuel

By Andrea Gaini

Above: Powdered feldspar samples from concentrated mine tailings

Researchers at the Queensland University of Technology (QUT), Australia, are using mining waste to fabricate a potentially "cheaper catalyst" for hydrogen fuel production.

The scientists have thermally modified chemically inert feldspars found in mining waste, such as albite and microcline. The *in situ* growth of more affordable transition metal nanoparticles, rather than noble metals, on these commonly available feldspar minerals is being used to promote electrocatalytic oxygen evolution reaction (OER) activity for electrochemical water splitting into hydrogen.

"A one-step thermal reduction method was used for the preparation of these new catalysts," says Professor Ziqi Sun from the QUT School of Chemistry and Physics.

During the process, the feldspar powders are dispersed with glucose and transition metal-containing salts. After sufficient adsorption and then drying, the feldspar powders loaded with nanoparticles of nickel, cobalt and iron are obtained by thermal annealing at 900°C for two hours under a continuous argon/hydrogen mixture gas flow. "This new nanocoated material triggers the OER, which controls the overall efficiency of the whole water splitting process," describes Sun.

The paper, published in *Advanced Energy & Sustainability Research*, reads, "The glucose used in this synthetic protocol has several crucial roles…1) ensuring homogeneous mix of feldspar mineral powders with metal-containing salts as aqueous dispersions, 2) mediating the metal nanoparticle-support interaction during the growth process, 3) reducing the size or dimension of the resultant transition metal particles under thermal reduction process, 4) carbonising and activating the electrochemical inert silicon oxide species within feldspar frameworks, and 5) stabilising transition metal nanoparticles by forming metal–carbon bonds.

"As a consequence, the resultant metal nanoparticles anchored onto feldspar mineral surfaces are favourable for OER, which greatly promotes the added value of the natural, abundant, low-cost, aluminosilicate minerals."

The feldspar powders occupy 99% of the overall catalysts in either weight or volume percentage.

The researchers have found that the cobalt nanoclusters decorated onto thermally reduced microcline (Co-KASO) are the most efficient among the examined metal-doped feldspars. They also suggest the Co-KASO catalyst performs better than conventional noble-metal-based catalysts, such as ruthenium oxide (RuO_2), without any modification to the hydrogen production process.

To trigger the requisite oxygen reduction reaction, Sun reports that the Co-KASO catalyst presents an overpotential of 330mV to reach 10mA cm^{-2} for a stable operation of 70 hours, while the referential RuO_2 catalyst needs an overpotential of 410mV. He says, "Co-KASO has a Tafel Slop of 50.6mV dec^{-1}, much better than that of RuO_2 of 90mV dec^{-1}, suggesting a favourable kinetic for industrial-scale catalysis…Of course, further optimisations or modifications are needed to push these catalysts into real applications."

He concludes, "We have demonstrated the possibility [of] the direct use of minerals or mining tailings, which opens a new window for the design of novel catalysts for fuel generations."

Sun now hopes to expand the database of suitable mineral and mining tailings for future materials selection.

Database tracks past tailings flows

A database is being developed at the University of Waterloo, Canada, to present a global picture of the occurrence rates, behaviours and physical impacts of mining tailings flows.

The aim is to help mining engineers compare the conditions of previous incidents to those of existing sites.

The study reports detailed information on 63 tailings flows that have occurred worldwide since 1928, analysed using historical satellite imagery. The research finds that, since 1996, the most frequent triggers for tailings flows have been hazardous weather and inadequate drainage systems, with excess stored water increasing the fluidity of failed tailings.

"Since 2014, there have been three high-profile events – two in Brazil and one right here in Canada," says Stephen Evans, a Professor of Geological Engineering at the University and co-author of the study. "While much progress has been made in terms of regulation and oversight, studying past tailings flows enables better prediction of what could happen should a major tailings impoundment failure occur."

3D printing titanium alloys

By Andrea Gaini

Pictured: The new titanium alloy developed using 3D printing has lava-like microstructures that enhance its mechanical properties

City University of Hong Kong

Additive manufacturing (AM), also known as 3D printing, can produce super-strong, highly ductile and ultra-light titanium alloys, according to a materials research team at City University of Hong Kong, China.

Researchers say the process produces titanium that is 40% lighter in weight, with lava-like microstructures exhibiting a high tensile strength of about 1.3GPa, a uniform elongation of about 9%, and work-hardening capacity of over 300MPa.

The process has been designed "using two commercial alloy powders: Ti-6Al-4V (Ti64) and 316L stainless steel," shares the paper, *In situ design of advanced titanium alloy with concentration modulations by additive manufacturing*, published in *Science*.

It reads, "We demonstrate an *in situ* design approach to make alloys spatially modulated in concentration by using laser-powder bed fusion. We show that the partial homogenisation of two dissimilar alloy melts allows us to produce micrometre-scale concentration modulations of the elements that are contained in 316L and in the Ti-6Al-4V matrix.

"The corresponding phase stability modulation creates a fine scale–modulated dual-phase microstructure that exhibits a progressive transformation-induced plasticity effect. This approach creates a pathway for concentration-modulated heterogeneous alloy design for structural and functional applications."

Dr Zhang Tianlong, a Postdoctoral Researcher at the University, explains that while AM has become more and more important in modern society, the success and wide application of metal-based AM has been severely hindered by the lack of printable alloys and the relatively poor mechanical properties of most AM-produced components.

He says, "People always consider 3D printing only as a shaping technology to form a complex component in one-step, without taking the full use of AM in alloy design. So, they only design materials for 3D printing, instead of designing materials by 3D printing.

"Metallurgists mostly consider that the inhomogeneities in alloy components are undesirable which leads to bad properties. In the AM community, one of the key issues is how to eliminate such inhomogeneity during fast cooling. However, seldom have the researchers tried to turn such waste into wealth.

"By controlling the fluid dynamics within the melt pool and creating alloys from partial homogenisation, we have achieved a gradient microstructure with a micrometre-scale concentration heterogeneity *in situ* throughout the bulk materials, which correspondingly leads to excellent structures and properties."

Tianlong explains that it is the iron concentration included in 316L powders that increases the supercooling capacity of the alloy melt during solidification, leading to finer solidification grain size. The iron concentration also plays an important role in determining the phase stability during fast cooling, which influences the final microstructure.

He says, this "alloy design strategy opens a new area of AM in the design of unprecedented alloys that are unachievable by any conventional methods.

"On the other hand, the designed titanium alloys with excellent properties are promising for structural applications in various scenarios, such as aerospace, automotive, chemical and medical industries".

The research team aims to now carry out more detailed tests of the properties under different circumstances, and explore their application in a range of alloy systems as well as application scenarios.

Also see Materials World, November 2021, for an article on 3D-printed copper-silver alloys at bit.ly/3n2MNIC.

Nanotwinning titanium

Cryo-forging is being used to manipulate pure titanium at nanometre scale at ultra-low temperatures to produce extra-strong 'nanotwinned' titanium without sacrificing its ductility.

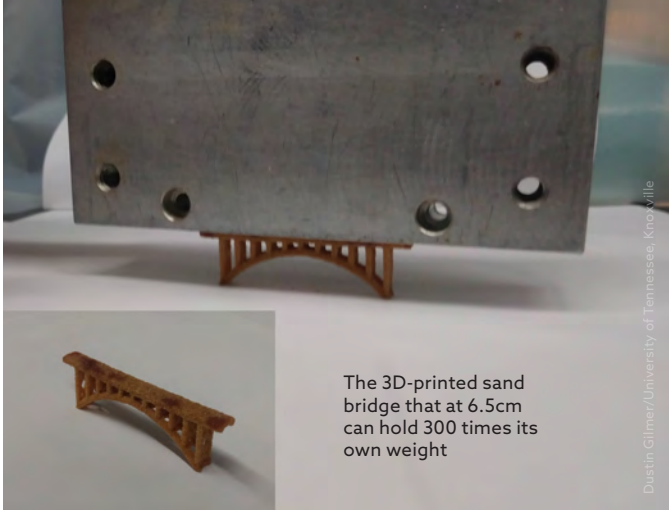
Researchers at the US Department of Energy's Lawrence Berkeley National Laboratory have found that nanotwinning doubles the metal's strength and increases its ductility by 30% at room temperature. At super-low temperatures, the improvement is even more dramatic – the material doubles in length before fracturing.

The scientists start with a cube of more than 99.95% pure titanium placed into liquid nitrogen at -160.5˚C. While the cube is submerged, compression is applied to each axis. Under these conditions, the material's structure begins to form nanotwin boundaries. The cube is later heated to 398.8˚C to remove any structural defects that form in between the twin boundaries.

During tests, the nanotwinned titanium is said to have shown formability as it can form both new nanotwin boundaries and undo previously formed boundaries, both of which help with deformation. Under temperatures up to 600˚C, it maintains its structure and properties.

Tailored polymer strengthens 3D-printed sand structures

By Andrea Gaini



The 3D-printed sand bridge that at 6.5cm can hold 300 times its own weight

Dustin Gilmer/University of Tennessee, Knoxville

Researchers are using a specially designed polymer to bind 3D-printed sand structures using the additive manufacturing technique of binder jetting.

Scientists from the Oak Ridge National Laboratory (ORNL), USA, have tailored polyethylenimine (PEI) to enable sand structures with intricate geometries and enhanced strength. It is said to double the strength of sand parts compared with conventional binders. The printable polymer is also water soluble.

The team explains how silica sand is an attractive material for binder jet printing because it is cheap and abundant, holds its shape when heated, and is washable with plain water. As an example, industries want to use it for composite tooling because sand shapes can be printed, wrapped in carbon fibre and cured, and then the sand is washed away with water. However, applications have been limited because current sand parts are not strong enough to support industrial needs at a large scale.

The binder jet printing, they add, is cheaper and faster than other 3D printing methods used by industry. The concept stems from inkjet printing, but instead of using ink, the printer head jets out a liquid polymer to bind a powdered material, such as sand, building up a 3D design layer-by-layer.

"The [new] binder works so well because of a unique chemistry that supports strong bonds with sand and reactivity with cyanoacrylate, a material commonly used in post-processing to make printed parts denser," says Tomonori Saito, Lead Researcher of the study.

The atomic interface between the binder and sand is critical. Silicate sand has a Si-O structure and PEI has -NH- in its structure. Upon curing, the structure rearranges to maximise the number of H-bonds between PEI and silicate, which forces the CH_2 groups in the PEI to contort into a corrugated-like structure to accommodate the H-bonding anchors. This corrugated interfacial structure facilitates densely packed and tightly bound H-bonding interactions of >N-H···O-Si between the cured PEI and silicate that lead to the enhanced mechanical strength.

"The binder acts like a glue, holding the sand together, as layers are built up to form 3D shapes. We discovered the optimal amount of PEI binder in the sand structure was 5.5wt.%," explains Tomonori.

Post-processing, cyanoacrylate is commonly used to strengthen printed parts, which are initially porous.

"One of our key findings was that, unlike conventional binders, the PEI binder reacts with cyanoacrylate to create very strong chemical bonds. Our untreated part was already stronger than unreinforced concrete, and on top of that, we saw an eight-fold strength increase with the cyanoacrylate step," Tomonori continues.

"The flexural strength was determined by three-point bend test. First, we showed the PEI binder for silica sand doubled the flexural strength of parts to 6.28MPa compared with that of the conventional binder (~3.6MPa), making it stronger than unreinforced concrete (~4.5MPa) in flexural loading. Next, we demonstrated that PEI in the printed parts reacts with cyanoacrylate in a post-processing step, resulting in an increase in flexural strength to 52.7MPa."

The team has demonstrated a 3D-printed sand bridge that at 6.5cm can hold 300 times its own weight.

The researchers say that this technology could be easily scalable to current manufacturing processes. Tomonori says, "It is really only limited by the size of your printer. For an example, in automotive and aerospace industries, the technology could accelerate parts production, meaning you could print an engine block or manifold for vehicles."

The team is now looking to further demonstrate the potential of this binder and expand the research to other powdered materials beyond sand that could be useful for a range of tooling and construction applications.

Popping corn for building insulation

Popcorn could act as an effective thermal insulator in buildings, say researchers from the University of Göttingen, Germany.

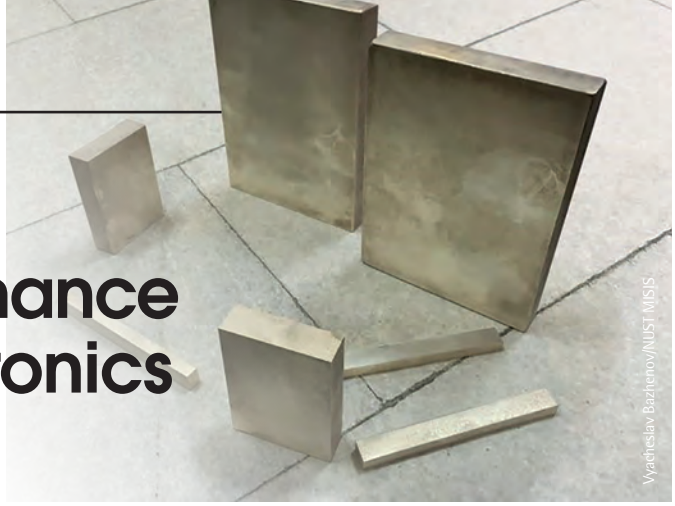
They claim that insulation boards made of granulated popcorn offer an environmentally friendly and a sustainable alternative to current products on the market.

"This new process, based on that of the plastics industry, enables the cost-effective production of insulation boards at an industrial scale," explains Professor Alireza Kharazipour from the University. "Especially in the field of insulation in construction, this ensures that natural insulation materials are no longer just niche products." In addition, the popcorn products have water-repellent properties.

The research group has recently agreed a licence agreement with the Bachl Group, Germany, for the commercial use of the process and the products for building insulation.

Magnesium alloys enhance heat removal in electronics

By Andrea Gaini


Vyacheslav Bazhenov/NUST MISIS

Above: Samples of magnesium, silicon, zinc and calcium alloy submitted to LG Electronics for testing

High-heat conductivity magnesium alloys that can reduce the weight of radiators and heat removal systems in electric vehicles and consumer electronics are being put forward by scientists in Russia.

To meet the rise in demand for efficient heat removal, researchers from the National University of Science and Technology (NUST MISIS), in collaboration with LG Electronics, have created two new magnesium alloys which they say offer a weight reduction of one third.

The first is made up of magnesium, silicon, zinc and calcium (Mg-Si-Zn-Ca), giving it thermal conductivity of 126W/mK, which is 81% of the thermal conductivity of pure magnesium, with average strength characteristics. While the second alloy comprises magnesium, zinc, yttrium and zirconium with a higher strength and slightly lower thermal conductivity of 105W/mK – 67% of pure magnesium.

Vyacheslav Bazhenov, Associate Professor at NUST MISIS, says, "The composition of the alloys selected was based on…calculations of the phase composition using the CALPHAD (CALculation of PHAse Diagrams) method.

"In the course of the development of highly heat-conducting magnesium alloys, the main concept was to provide strengthening of a magnesium solid solution with the help of elements that reduce the thermal conductivity of pure magnesium to the least degree. We also tried to achieve the formation of a large amount of the eutectic phases in the structure of the alloy, providing good casting properties."

Bazhenov notes that aluminium heat sinks are most commonly used for heat dissipation, but due to global trends in environmental regulation and the need for lighter materials in electronics, alternative materials are being explored.

"Among the materials that can provide a weight reduction compared to aluminium alloys for heat sinks, magnesium alloys and high thermal conductivity plastics can be distinguished."

Using plastics is challenging due to their lack of strength, Bazhenov explains, while magnesium alloys traditionally tend to have low thermal conductivity.

"For the development of the alloys, we used the alloying elements that have a minimal effect on magnesium thermal conductivity (zinc and yttrium), as well as elements that practically do not dissolve in magnesium (silicon and calcium). This combination helped us achieve the desired result, namely a combination of a high level of mechanical and technological properties while maintaining high thermal conductivity.

"In contrast to currently used aluminium alloys with a density of 2.7 g/cm^3, the developed magnesium alloys have a density of 1.8 g/cm^3 …At the same time, the mechanical properties (if we compare the casting aluminum and magnesium alloys) remain at the same level."

The addition of calcium and yttrium also tackles another issue. "The main problem with the manufacture of products from magnesium alloys and their operation is their flammability…The oxide film on the surface of magnesium alloys is broken and provides no protective effect (low value of the Pilling-Bedworth ratio). We have decided to use the additives of yttrium and calcium, which replace a significant part of the magnesium in the oxide film and make it denser (increase the Pilling-Bedworth ratio)."

LG has tested the technological properties of the Mg-Si-Zn-Ca alloy at one of its facilities and samples have been obtained in an industrial high-pressure die casting machine. Bazhenov concludes, "The technological properties of the developed alloy turned out to be practically the same as the properties of the most widespread casting magnesium alloy in the industry (AZ91), which means that it is suitable for the manufacture of products of very complex shapes."

Driving forward aluminium batteries

Scientists at Cornell University, USA, have incorporated aluminium into rechargeable batteries using carbon fibre, offering up to 10,000 error-free cycles.

The team explains that previously aluminium has been difficult to integrate into a battery's electrodes because of its chemical reactions with the glass fibre separator, causing the device to short circuit and fail.The solution put forward is a substrate of interwoven carbon fibre that forms a stronger chemical bond with aluminium. When the battery is charged, the aluminium is deposited into the carbon structure via covalent bonding.

While electrodes in conventional rechargeable batteries are only 2D, this technique uses a 3D – or non-planar – architecture that creates a deeper, more consistent layering of aluminium that can be finely controlled.

"Basically, we use a chemical driving force to promote a uniform deposition of aluminium into the pores of the architecture," explains Jingxu (Kent) Zheng, lead author of the research project. "The electrode is much thicker, and it has much faster kinetics." The aluminium-anode batteries can be reversibly charged and discharged at one or more orders of magnitude than other aluminium rechargeable batteries.

Heads up – 3D holographic display for road safety

A light detection and ranging (LiDAR) head-up display could improve road safety by 'seeing through' objects to alert the driver of potential hazards using augmented reality.

This could be particularly useful where road signs are hidden by large trees or trucks, allowing the driver to 'see through' visual obstructions.

The technology, developed by researchers from the UK Universities of Cambridge, Oxford and University College London, uses LiDAR data to create ultra-high-definition holographic representations of road objects that are beamed directly to the driver's eyes, instead of 2D windscreen projections used in most head-up displays.

While the technology has not yet been tested in a car, early studies, based on data collected from a busy street in central London, show that the holographic images appear in the driver's field-of-view according to their actual position, creating an augmented reality.

The optical set-up is capable of projecting multiple layers of holograms with the help of advanced algorithms, while the projection can appear in different sizes.

Mechanically imprinting dislocations in electroceramics

by Andrea Gaini

Pictured: A barium titanate ($BaTiO_3$) single crystal before deformation

Marion Höfling

Dislocations are being mechanically imprinted into single-crystal bulk ceramics to enhance their electromechanical properties.

Researchers from the Technische Universitat Darmstadt, Germany, suggest that such dislocations effectively interact with ferroelectric domain walls on an atomic scale, as well as affecting the macroscopic domain structure and increasing the piezoelectric coefficient.

They have tested this on barium titanate ($BaTiO_3$) as it allows dislocations to be introduced into the material, limited by the available and active slip systems, while also having a non-centrosymmetric structure for piezoelectric behaviour.

"The location and distribution of the dislocations in the material (and thus of the atoms) is based on the existing slip systems, which in ceramics are limited by ionic and covalent bonds…The basic idea was to find a new method to modify the motion of the ferroelectric domain walls, since this is crucial for the electromechanical performance of the material," says Marion Höfling, Researcher at the University.

"The concept is based on the mechanical imprinting of dislocations into the ceramic, which is a new approach in the field of functional ceramics."

The ceramics are mechanically deformed under controlled pressure and temperature conditions so the displacement can be imprinted. The team explains that, until now, it was largely deemed impossible with ceramics because of their hardness and brittle surface. To overcome this, a mechanical imprint is made at 1,150°C in a single crystal in a previously calculated optimised orientation.

This method now allows a well-ordered field of newly occupied atomic rows. These series control the local polarisation – the load dislocation – in the material. In the operation of electroceramics, the material areas now delimited by the series (displacements) take up certain charge shifts, and as these material areas do not change under high operating conditions, no energy is converted by internal friction and the material behaviour remains stable.

Höfling continues, "Modification of electromechanical properties in functional ceramics such as piezoelectric and ferroelectrics is usually based on point defect doping or chemical modifications, which are 0-dimensional defects. Therefore, considering dislocations as possible stabilising defects in a material commonly considered 'brittle' is a new perspective. In contrast to point defects, dislocations have the advantage of being more temperature stable, exhibiting good cycling stability, and requiring less complex chemical compositions due to the fact that line defects are intrinsic defects.

"The basic concept of dislocations (Burgers vector, screw and edge type, etc.) is the same as in metals with the difference that the dislocation core can be charged and that they may have a charged space charge zone in the surrounding."

Höfling explains that the mechanical dislocation imprint for functional property modification is inspired by plastic deformation in metals, creep studies in geology, and defect engineering in piezoelectric and ferroelectric oxides.

She notes that electroceramics fabricated using standard approaches often have some drawbacks in performance or secondary requirements such as cycling and temperature stability.

The scientists have tested the dislocations with transmission electron microscopy and phase field simulations. They are currently seeking to implement it in polycrystalline materials to allow easier transfer to real applications.

Höfling concludes, "The goal of this basic research is that in the future materials can be modified to replace some of the commonly used toxic piezoelectric materials with even better properties.

"A five-times increase in dielectric properties and almost 20-times increase in piezoelectric performance, enables [us] to make more efficient (and thus smaller) dielectric capacitors and piezoelectric motors."

Hard disks jump forward with graphene

Graphene could be used for ultra-high density hard disk drives (HDD) with up to a 10-fold jump in data density compared to current technologies, say researchers at the Cambridge Graphene Centre, UK.

The scientists have replaced commercial carbon-based overcoats on hard disks made of iron-platinum for magnetic recording with one to four layers of graphene, and tested friction, wear, corrosion, thermal stability and lubricant compatibility.

The use of graphene is said to deliver a two-fold reduction in friction and 2.5 times reduction in corrosion and wear.

The team has tested for heat-assisted magnetic recording (HAMR) – a technology to increase storage density by heating the recording layer to high temperatures. Graphene, coupled with HAMR, is projected to outperform current HDDs, providing data density higher than 10 terabytes per 6.45cm^2.

VTT

Left: Granulated zinc-containing dust used in laboratory scale testing

Dusting off the steel industry

by Andrea Gaini

Zinc dust from the steel industry is being targeted for sulphur removal during biomass gasification.

Researchers at the Technical Research Centre of Finland (VTT) claim that side-streams containing zinc could be as efficient for synthesis gas purification as current commercial zinc oxide products.

Zinc dust contains small solid particles that hang in the air and slowly settle on surfaces. If inhaled, it may have significant adverse health effects. The finest material is usually the most difficult to treat and recirculate.

"The treatment process of the side-stream into a new product is relatively simple and although [it] contains [material] other than…zinc compounds, they don't fundamentally hinder the processability…into desired shape and size," says Lintunen Pertti, Senior Scientist at VTT.

The dust collected at steel plants is said to be of "interesting" composition and suitable for granulation/pelletisation.

"The technology was tested in laboratory-scale desulphurisation… [where] adsorbents made from zinc-containing dusts were compared to commercial adsorbents by measuring the sulphur capture capacity for both in same testing conditions."

In the best case, Pertti explains, zinc-containing dust shows sulphur capture performance that is 66%/92% on mass/volume basis, respectively, compared to a commercial adsorbent.

"This is a really promising result for steel industry side-stream sometimes considered as a waste material," adds Björn Haase, Manager of Non-Metal Products, Höganäs Sweden AB, which provides the zinc-containing side stream from their factory to be used in the project.

The steel industry in Europe generates several thousand tonnes of zinc-containing dust each year, which, at its worst, is treated as hazardous waste. The treatment of hazardous waste is expensive and the environmental load high.

VTT Research Scientist Minna Kotilainen says this new purpose for zinc dust could help substitute at least part of the primary zinc oxide used in commercial adsorbents, and reduce the price of absorbing pellets, as well as lowering the environmental load.

Research Team Leader Tomi Lindroos continues, "[The] next step will be finding a suitable processing route for zinc-containing dust to manufacture adsorbents in an economically feasible way and in higher volumes."

Photocatalyst doubles methane fuel production

A novel photocatalyst can produce methane fuel (CH_4) selectively and effectively from CO_2 using sunlight, say scientists at City University of Hong Kong (CityU).

The quantity of methane produced is said to have almost doubled in the first eight hours of the reaction process.

The photocatalyst is fabricated by enwrapping cuprous oxide with copper-based metal-organic frameworks (MOFs) to manipulate the transfer of electrons and selectively produce pure methane gas.

Dr Ng Yun-hau, Associate Professor at CityU, says, "Inspired by the photosynthesis in nature, CO_2 can now be converted effectively into methane fuel by our newly designed solar-powered catalyst, which will lower carbon emissions. Furthermore, this new catalyst is made from copper-based materials, which is abundant and hence affordable."

The team has discovered that cuprous oxide with a MOF shell reduced CO_2 into methane stably under visible light irradiation with an almost doubled yield, compared to that without a MOF shell.

Tackling nitrogen and carbon industrial emissions

A Bi-$BiVO_4$ Mott-Schottky heterostructure catalyst is converting nitrogen (N_2) and carbon dioxide (CO_2) into urea molecules in ambient conditions. This is achieved via a C-N coupling reaction to reduce industrial emissions.

A research team led by Professor Zhang Guangjin from the Chinese Academy of Sciences says the spontaneous charge transfer at the heterointerfaces promotes the formation of space-charge region. "The space-charge region not only facilitates the targeted adsorption and activation of CO_2 and N_2 molecules on the generated electrophilic/nucleophilic regions, but also effectively suppresses CO poisoning and the formation of endothermic *NNH intermediate," says Zhang.

The adsorbed $*N_2$ can promote CO_2 reduction to form CO, and then the generated CO will further react with $*N_2$ to produce the desirable *NCON* intermediate via electrochemical C-N coupling reaction.

"The subsequent protonation process preferentially undergoes the alternating mechanism until the formation of urea," says Zhang.

The researchers have used linear sweep voltammetry (LSV) to preliminarily evaluate the performance of urea electrosynthesis with Bi-$BiVO_4$ hybrids.

Sea change for zinc oxide production

By Andrea Gaini

Chemical engineers claim to have developed a method of manufacturing zinc oxide (ZnO) for health and beauty products, such as sunscreen, that requires 95% less energy and is more cost effective. The scientists, from the University of Sheffield and Imperial College London, UK, note this could eliminate the "devastating impact" of chemical-based sunscreens on marine life.

The technique is called Oxidative Ionothermal Synthesis (OIS). Dr Kyra Sedransk Campbell, a Research Fellow at the University of Sheffield, explains, "There are currently two categories of ZnO available on the market – mass (bulk) produced and advanced. The former is offered in limited grades and is produced without a view towards specificity. These products are low in price, but also low in quality and performance…using extremely energy intensive processes.

"The end-users using this product either cannot afford a higher priced and better performing material, or are satisfied as they may not be aware that a better alternative is available.

"In the latter category, the specification for advanced zinc oxide requires complex techniques which often cannot be scaled, and therefore a high price is commanded."

Campbell describes, "This new technique is…a one-pot method that uses water blended with ionic liquids to create a specific environment for the nucleation and growth of zinc oxide. This careful control allows us to achieve specificity in the products made…[It is a] flexible manufacturing method that can enable production of a wide range of particle types – very unusual for a wet-chemistry method in which analysing is done in the liquid phase.

"…and we start with a solid precursor (rather than a salt). This is an important removal of a step (solid precursor → salt) that requires energy and therefore has an environmental footprint itself."

The OIS method dramatically reduces energy needs by operating at relatively low pressures, Campbell adds.

The researchers convey the importance of energy and cost efficient manufacture of ZnO by explaining how alternative low-cost sunscreens contain chemicals that impact on marine life, such as the bleaching of coral reefs. Meanwhile, high-end sunscreens that contain zinc oxide avoid such effects on the environment. "The market is predominantly made up of the chemical sunscreens because the price point is significantly lower than that of mineral-based sunscreens," asserts Campbell.

She says that, although their products cross into the advanced materials category, "because it is a one-pot method, we have confidence that the translation [in the market] should be relatively straightforward".

Cinoby/Getty

Zinc oxide is used across a wide range of applications including tyres, paints, personal care products, sensors, etc. There is also a growing interest in zinc oxide for battery applications.

"The new technique…offers a sustainable method for manufacturing zinc oxide. Moreover, it has an inherent flexibility to make a wide range of structures with limited tuning required. The latter point is essential as it makes the technology scalable whilst also simultaneously offering flexibility towards different end products," Campbell adds.

The team has now launched a start-up company to commercialise the technique, called Nanomox. "The company's first target is to demonstrate the scalability of producing zinc oxide using this OIS method. This will then provide them with additional material in a sufficient quantity so that they can do more testing to work with partner companies towards delivering both more sustainable and higher specification products.

"We have [also] demonstrated in some preliminary tests that we are able to use recycled products as our starting material and, potentially, use waste streams containing zinc. With the expansion of this work it suggests that we could, effectively, upcycle recycled/waste zinc into a high value commodity."

Bacteria aids copper's transformation

Researchers from the University of Houston, USA, and the University of São Paulo, Brazil, have discovered that bacteria in a mine in Brazil converts copper sulphate ($CuSO_4$) ions into zero-valent Cu (metallic copper).

"We found out the bacteria were isolating single-atom copper. In terms of chemistry, this is extremely difficult to derive. Typically, harsh chemicals are used in order to produce single atoms of any element. This bacterium is creating it naturally – that is very impressive," says Dr Francisco Robles Hernandez, from the University of São Paulo.

Dr Debora Rodrigues at the University of Houston adds, "The microbes utilise a unique biological pathway with an array of proteins that can extract copper (II) (Cu^{2+}) and convert it into single-atom zero-valent copper (Cu^0). The aim is to create a less toxic environment for themselves by converting the ionic copper into single-atom copper, but at the same time they make something that is beneficial for us too."

European consortium strives for carbon-neutral mining

Epiroc, a productivity partner for mining, is leading a new EU-funded project to implement more carbon neutral and efficient processes in the industry.

The project will incorporate battery-electric mining equipment, full usage of 5G for optimal connectivity and positioning, autonomous material handling, artificial intelligence-powered traffic and fleet control, and collaboration among machines.

The three-year programme, called NEXGEN SIMS, is an initiative between European mining companies Boliden, Agnico Eagle Finland, KGHM Polska and K+S, and Australian mining company, OZ Minerals. The consortium also brings together services and system suppliers including Ericsson, Mobilaris MCE, AFRY and KGHM Cuprum, as well as Luleå University of Technology, Lithuania, and RWTH Aachen University, Germany.