

chemistry

June–August 2023

in Australia

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cover story

Construction and deconstruction: materials and substances from 'waste'

Transitioning to 'no waste' can be a complex task, so University of Southern Queensland researchers at the SIMPLE hub and NO WASTE pilot precinct are aiming for simple design, processes and recovery to keep 'waste' out of landfill.

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22 Advancing our transition to a greener plastics future

At the ARC Industrial Transformation Training Centre for Bioplastics and Biocomposites, PhD candidates and early career researchers are addressing the wicked problem of plastics waste.

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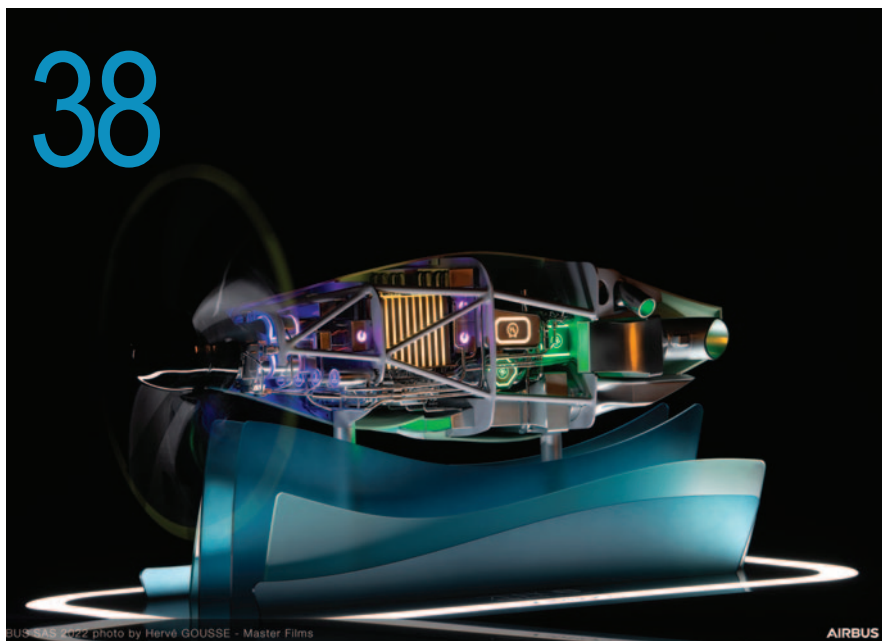
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Chemistry solutions to societal challenges

Two things have particularly stood out to me as RACI President since I last wrote for *Chemistry in Australia*. First is that the voice of RACI is being heard more strongly: our submission to the ARC review was highlighted in the recommendation of the ARC review panel led by Professor Margaret Sheil FRACI CChem and our submission to the Chief Scientist's review of Australia's Science and Research Priorities has led to an invitation to join a workshop about the next in that review. Second is the experience gained from the RACI President and CEO national tour, which is now coming to an end. Let me expand further below on the Science and Research Priorities and some initial thoughts from our national tour.

Chemistry can provide many solutions to societal challenges. This was the key message from RACI in its submission to the review of Australia's Science and Research Priorities and National Science Statement. RACI went on further to point out that we, our bodies and almost everything that we care about in this world is made from chemicals. Chemistry holds the key to both understand and then solve several key societal challenges, including the climate change crises and a range of health and well-being challenges. To move forward, we believe that Australia needs to understand better the important role that science, including chemistry, plays everywhere in society, be it in industries, our daily lives and well-being, or – at a more philosophical level – in understanding the world around us. RACI is therefore of the view that chemistry can provide solutions to what we see as key national challenges and potential priorities for the ongoing discussions regarding Australia's Science and Research Priorities, namely:

- providing innovative solutions to the climate change crises
- improving the well-being and health of our citizens
- embracing the role of science to improve society.

From branches in big cities to the smallest regional sub-groups, we found that for many RACI members the organisation is first and foremost *their community*.

The national tour has underlined the above thinking. This tour has taught me personally a lot more about how chemists around the country are developing solutions to societal challenges every day. From Darwin to Hobart and from Brisbane to Perth, researchers are working on sustainable chemistry, better environmental monitoring, novel medicinal chemistry and chemistry outreach in regional and rural areas. What really has struck though is how vibrant and how diverse our chemistry communities around the country are! From branches in big cities to the smallest regional sub-groups, we found that for many RACI members the organisation is first and foremost *their community*.

As I write this, I am leaving Darwin, with only Townsville and Sydney left on our itinerary. We started in Adelaide, then visited Melbourne, Hobart, Brisbane, Perth, Canberra and Darwin. In all the chemistry communities we have visited so far, we asked what the National Office and National Board can do to help the communities do their work better. What should RACI be doing (more of) for their members? The National Board and CEO Shenal Basnayake will be digesting the feedback from these meetings and from other discussions with members over the next few months. But it is clear already that one of the highest priorities will be to continue to support community events across the country. The Branch, Group and Divisional meetings and activities is the beating heart of RACI. Yes, we need to make our voice more strongly heard – be it in government or in industry. We also need to strengthen and broaden activities for our younger and emerging chemists – be it social events, training or mentoring programs. But at the same time, we need to provide even better support to our communities to allow them to do what they do best – run activities and meetings that bring their communities together.

Chemistry is everywhere and chemistry can provide many solutions to societal challenges. RACI is and continues to be the best avenue for all chemists in Australia to work together on these challenges and have our voice heard. Onwards and upwards for chemistry in Australia!



Pall Thordarson FRACI CChem (president@raci.org.au) is RACI President.

Industry membership – some thoughts for food

In the March–May edition of *Chemistry in Australia*, Richard Thwaites' article 'Australian chemical organisations: a remedy for fragmentation' (p. 38) invoked for me a subject that I have been contemplating for several years, namely the status of RACI members employed in industry.

I have spent 55 of the past 61 years in the food and pharmaceutical industries, with four and a half rewarding and enjoyable years at CSIRO and one year in a teaching laboratory at the University of Melbourne. I joined RACI because I thought membership may be an asset when I was considering moving overseas in the 1970s.

My involvement with RACI has been a little sparse as I became very involved with Australia Institute of Food Science and Technology and Food Technology Association Australia. However, I have always valued my 50 years of RACI membership.

The main benefits of RACI to me have been the monthly magazine (now quarterly), which, in my opinion, has improved greatly over the past several years under the editorship of Sally Woollett, and networking, particularly lately with the retired members group.

With the assistance of Robyn Taylor (2015), Richard Thwaites and Roger Stapleford (2023), I discovered that RACI has about 4500 members of whom 40–60% are from industry. Real numbers are difficult to obtain due to privacy and how to classify and define all the various categories including academics, government, teachers, students etc. (Disclosure statement: Richard and I worked for sister companies way back in the 1970s and 80s, as part of the ICIANZ conglomerate.)

Nevertheless, RACI has a large industry membership, which as Richard stated in his article, could be greatly enhanced through cooperation with other organisations.

Also in the March–May edition are the recipients of the RACI National Awards, who should all be congratulated. Of the 23 members whose efforts and successes are described, only four are not designated as being currently employed at a tertiary institute/university: two of the Citations Awards, the Ochre Award and the Vicki Gardner Advocacy Award.

Although the ability to be a recipient of an RACI award is not an incentive to join RACI, the question is begged, are the RACI industry members fairly represented in the annual awards? I believe RACI management should be specifically reviewing the benefits of RACI to the 50% membership from industry, particularly the annual awards.

It is appreciated that industry members cannot disclose or publish their in-house R&D and application developments, often utilising the results of research undertaken in academia; however, industry members can and do contribute in other ways in the chemistry world and for the benefit of many population groups. As an example, I noted that in Dave Sammut's article in the March–May issue, 'A decade of making a difference' (p. 26), all the people mentioned as mentors came from industry.

Anthony F. Zipper FRACI CChem

Contaminating space

I might be able to add a point of interest to Ralph Cooney's article about human-generated debris in space (March–May issue, p. 31). In my recent treatise *The application of nuclear science to space* (BookBoon, Frederiksberg, 2022), I discuss how rovers and landers travelling from Earth to Mars will carry with them microbes that could escape into the Martian terrain and survive and propagate. Measures are being taken to prevent such contamination and NASA requires that spacecraft departing for Mars be examined and evaluated for bioburden.

Clifford Jones FRACI CChem

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Health of coral reefs written in the sand

How healthy are coral reefs? And how are they responding to climate change? After more than 10 years of monitoring the Great Barrier Reef, University of Sydney geoscientists have developed a technique that allows them to answer these questions using satellites. And it all relies on sand aprons.

Sand aprons, deposits of sand along the shore of a lagoon that are ubiquitous in coral reefs, can give a reliable estimate of how coral reefs are growing, as well as their rate of carbonate sediment productivity – key to establishing their overall health.

‘The traditional way of collecting such data is very work intensive’, said Associate Professor Ana Vila-Concejo, who led the study, published in *Geology* (doi.org/10.1130/G50453.1). ‘It requires actively measuring the chemistry of water or taking thousands upon thousands of photos to calculate how much each creature in the ecosystem is contributing to carbonate sediment productivity.’

But the study also found more signs of trouble for coral reefs: carbonate productivity today is half what it has been for thousands of years of sand apron formation in the southern Great Barrier Reef. ‘Our results suggest that ecosystem health was much better then, so we’re likely seeing the effects of climate change in our present-day data’, added Vila-Concejo.

How corals grow and recede, and under what conditions, and how healthy they are, depends on an incredibly complex combination of factors – such as waves and storm surges, sedimentation rates, seawater chemistry, land-based run-off and even fish populations. Hence, predicting the health of any single coral reef group, and how it will respond to climate change, is an intricate puzzle.

However, the researchers found that sand aprons – formed as waves and currents from reef crests carry sediment that becomes trapped in the reef lagoons – can be used to estimate carbonate productivity over time, and



Coring sand aprons at One Tree Island, Great Barrier Reef.

therefore the health of a coral ecosystem.

The field team, coordinated by Dr Sarah Hamylton, worked from a 12-metre catamaran to visit 21 reefs in the southern Great Barrier Reef, collecting more than 100 000 records of reef bathymetry and composition.

The team later worked with satellite imagery to measure the sand aprons and estimate their volume for each reef. They then matched that data with carbonate production measurements taken over more than a decade to try and understand sand apron evolution, and how it correlated with productivity.

‘The formation of sand aprons by lagoon infilling is a function of reef size, and a self-limiting process controlled by the surrounding hydrodynamics and in response to the ebb and flow of sea-level changes’, said Vila-Concejo, who is also Deputy Director of the One Tree Island Research Station, located in the Great Barrier Reef. ‘If we can understand the evolution of sand aprons in each reef over time, we can use the data to manage coral reefs and prepare for climate change.’

As coral reefs around the world

respond to warming oceans, it will change how corals behave. The climate effects on the drivers for sand apron development – sediment production, hydrodynamic forcing, and the infilling of lagoons – are not yet clear. But the study indicates that understanding their behaviour and evolution provides a powerful shortcut to determining overall reef health.

In addition, by combining modern analysis of sand apron accretion with data going back 8000 years, the researchers can establish the background rate of coral productivity.

‘Our findings show that the carbonate production was much higher during the Holocene – the last 11 700 years of Earth’s history – but that the average rate of production today is down 50% on this. That is a cause for concern’, Vila-Concejo said.

‘Our current research involves modelling what this will mean for the future of the Great Barrier Reef, and these data are going to be essential for that’, she added.

University of Sydney

Light-based tech possibilities in space and agriculture

Super-thin chips made from lithium niobate are set to overtake silicon chips in light-based technologies, according to scientists in the field, with potential applications ranging from remote ripening-fruit detection on Earth to navigation on the Moon.

The scientists say the artificial crystal offers the platform of choice for these technologies due to its superior performance and recent advances in manufacturing capabilities.

RMIT University's Distinguished Professor Arnan Mitchell and the University of Adelaide's Dr Andy Boes led this team to review lithium niobate's capabilities and potential applications in *Science* (doi.org/10.1126/science.abj4396).

The international team, including scientists from Peking University, China, and Harvard University, USA, is working with industry to make navigation systems to help rovers drive on the Moon later this decade. As it is impossible to use GPS technology on the Moon, navigation systems in lunar rovers will need to use an alternative system, which is where the team's innovation comes in.

By detecting tiny changes in laser light, the lithium niobate chip can be used to measure movement without needing external signals, according to Mitchell.

Mitchell said that while the lunar navigation device was in the early stages of development, the lithium niobate chip technology was 'mature enough to be used in space applications'.

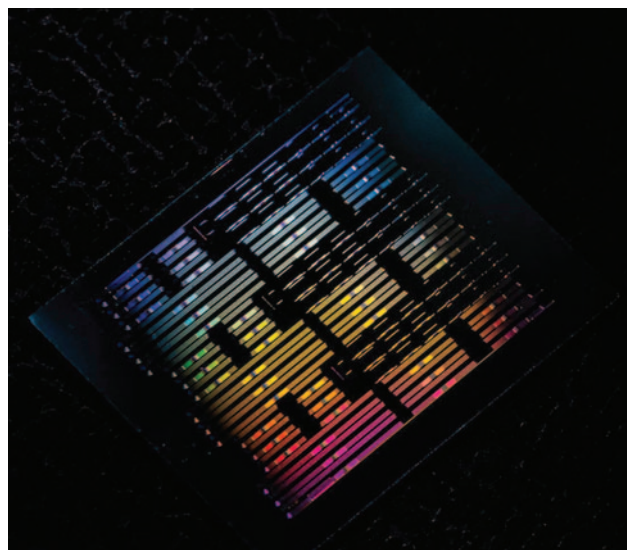
'Our lithium niobate chip technology is also flexible enough to be rapidly adapted to almost any application that uses light.'

According to Boes:

'Lithium niobate has come back into vogue because of its superior capabilities, and advances in manufacturing mean that it is now readily available as thin films on semiconductor wafers. Photonic circuits are printed into the lithium niobate layer, which are tailored according to the chip's intended use. A fingernail-sized chip may contain hundreds of different circuits.'

The team is working with the Australian company Advanced Navigation to create optical gyroscopes, where laser light is launched in both clockwise and anticlockwise directions in a coil of fibre, Mitchell said.

'As the coil is moved, the fibre is slightly shorter in one



This chip is the size of a fingernail and is made on thin film lithium niobate. It can be used for data communications or biological sensing.

RMIT University

direction than the other, according to Albert Einstein's theory of relativity', he said.

'Our photonic chips are sensitive enough to measure this tiny difference and use it to determine how the coil is moving. If you can keep track of your movements, then you know where you are relative to where you started. This is called inertial navigation.'

This technology can also be used to remotely detect the ripeness of fruit.

'Gas emitted by ripe fruit is absorbed by light in the mid-infrared part of the spectrum', Mitchell said.

'A drone hovering in an orchard would transmit light to another, which would sense the degree to which the light is absorbed and when fruit is ready for harvesting.'

Australia could become a global hub for manufacturing integrated photonic chips from lithium niobate that would have a major impact on applications in technology that use every part of the spectrum of light, Mitchell said.

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Hydrogen–boron fusion measured in magnetically confined fusion plasma



Inside the Large Helical Device Control Room at the National Institute for Fusion Science, Japan. From left: Richard Magee and Hiroshi Gota (TAE Technologies), and Mitsutaka Isobe, Kunihiro Ogawa and Masaki Osakabe (NIFS).

TAE Technologies and Japan's National Institute for Fusion Science (NIFS) have conducted the first hydrogen–boron fusion experiments in a magnetically confined fusion plasma.

In a paper published in *Nature Communications* (doi.org/10.1038/s41467-023-36655-1), scientists explain the outcome of the nuclear fusion reaction of hydrogen–boron in an experiment in NIFS's Large Helical Device (LHD). This paper describes the experimental work of producing the conditions necessary for hydrogen–boron fusion in the LHD plasma and TAE's development of a detector to make measurements of the hydrogen–boron reaction products: helium nuclei (alpha particles). The finding reflects years of collaborative international scientific fusion research, and represents a milestone in TAE's mission to develop commercial fusion power with hydrogen–boron.

'This experiment offers us a wealth of data to work with, and shows that hydrogen–boron has a place in utility-scale fusion power', said Michl Binderbauer, CEO of TAE Technologies.

More than 30 groups around the world are pursuing the development of fusion energy, and approaches vary widely, from reactor configuration to the type of fuel the future reactors will rely on. TAE is currently building and designing two more machines, Copernicus and Da Vinci, which will be able to

demonstrate net energy and deliver power to the grid, respectively.

Inventing fusion reactors that produce net energy is one thing; delivering it as a reliable, grid-ready source of electricity is another. Most fusion efforts are focused on combining hydrogen isotopes deuterium–tritium (D-T) to use as fuel, and the donut-shaped tokamak machines commonly used in fusion concepts are limited to D-T fuel. TAE's design uses an advanced accelerator beam-driven field-reversed configuration that can accommodate all available fusion fuel cycles, including hydrogen–boron ($p\text{-}^{11}\text{B}$), D-T and deuterium–helium-3 ($\text{D-}^3\text{He}$).

As the paper in *Nature Communications* puts it: 'While the challenges of producing the fusion core are greater for $p\text{-}^{11}\text{B}$ than D-T, the engineering of the reactor will be far simpler. ... Stated simply, the $p\text{-}^{11}\text{B}$ path to fusion trades downstream engineering challenges for present-day physics challenges. And the physics challenges can be overcome.'

While this reaction did not produce net energy, it demonstrates viability of aneutronic fusion and reliance on hydrogen–boron. TAE expects to demonstrate net energy on its next research reactor, Copernicus, around mid-decade.

TAE Technologies

First synthesis of a compound with aromatic nitrogen rings

An international team with researchers from the University of Bayreuth, Germany, has presented a potentially groundbreaking discovery for nitrogen chemistry in *Nature Chemistry* (doi.org/10.1038/s41557-023-01148-7): for the first time, a compound containing aromatic rings of nitrogen atoms has been synthesised.

The compound of nitrogen and potassium was produced under extremely high pressures and temperatures. A major component of its complex structure is a hexazine anion, a planar ring of six nitrogen atoms.

Numerous systems composed of carbon heterocycles and non-carbon cycles can have an aromatic character. Nitrogen aromaticity, however, has so far been restricted to the $[\text{N}_6]^{4-}$ pentazolate anion.

An international collaboration, involving the Laboratory of Crystallography and the Bavarian Research Institute of Experimental Geochemistry and Geophysics (BGI) at the University of Bayreuth, has now led to a considerable breakthrough. Under extreme pressure and temperature conditions, the complex compound K_9N_{56} , which contains $[\text{N}_6]^{4-}$ hexazine rings, was synthesised.

The structure of K_9N_{56} is a complex arrangement of $[\text{N}_6]^{4-}$ and $[\text{N}_5]^-$ rings as well as neutral nitrogen dimers. The

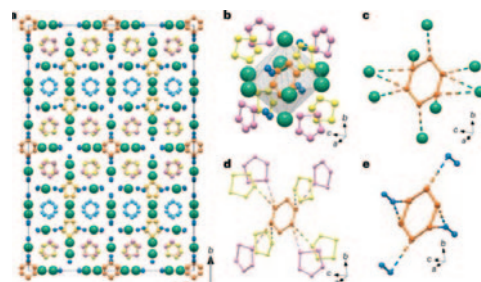
researchers found that Hückel's rule applies to the structure of the $[\text{N}_6]^{4-}$ hexazine ring: the ring is cyclic and planar and has $(4n + 2) \pi$ -electrons (10π system).

'This is the first time that a ring consisting of six nitrogen atoms has been synthesised that follows the Hückel rule for aromaticity. Its aromatic character is further supported by bond-length considerations and by calculations of the electronic charge density', said Professor Dr Natalia Dubrovinskaya of the Laboratory of Crystallography.

'This study provides a striking example contradicting the trope of structural simplicity at high densities. We hope that this synthesis of the aromatic hexazine anion, together with that of the aromatic $[\text{N}_5]^-$ pentazole anion, can stimulate further exploration of nitrogen chemistry in the search of novel nitrogen-based technological materials', added Professor Dr Leonid Dubrovinsky of BGI.

The complex compound K_9N_{56} was formed under unusual conditions: potassium azide (KN_3) and molecular nitrogen (N_2) were compressed at pressures of 46 and 61 gigapascals and heated to 2000°C with high-powered lasers.

The next step was to elucidate the internal structure of this new compound. To do this, the samples were exposed to an intense X-ray beam at two particle



The experimentally determined crystal structure of the K_9N_{56} compound at 61 GPa by SC-XRDp. *Nature Chemistry*

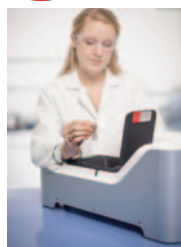
accelerators, the PETRA III X-ray source at the German Electron Synchrotron in Hamburg and the European Synchrotron Radiation Facility in Grenoble.

'We were very surprised about the atomic arrangement of the compound K_9N_{56} : it is of a complexity almost never observed for solids produced at such high pressures. We found that it is composed of a repeating arrangement of 520 atoms at 72 kelvin and 448 newtons. Although we could immediately see that the planar $[\text{N}_6]^{4-}$ rings were fulfilling the basic requirements for aromaticity, we applied advanced calculations methods to verify this', reported Dr Dominique Laniel of the University of Edinburgh, first author of the paper.

University of Bayreuth



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Ian Hansen, CEO Wesfarmers Chemicals, Energy & Fertilisers (WesCEF), accepting Chemistry Australia's inaugural Hall of Fame award.

Chemistry Australia inaugural industry awards

Excellence in the Australian chemistry industry was celebrated in April with five outstanding individuals and organisations recognised for their achievements in the first Chemistry Australia Industry Awards.

Held at the Pavilion, Melbourne Arts Centre, the 2023 Industry Awards acknowledged the achievements of the sector's best and brightest from the diverse range of businesses across Chemistry Australia's membership.

With the theme of 'future industry', the Awards recognised achievements to significantly reduce emissions, support an Australian circular economy, and protect the health and safety of workers, communities and the environment. Young leaders in the industry were also celebrated for their contribution to their businesses and the community.

Awards were presented across five categories: Net Zero Transition; Circular Economy; Health, Safety and Environment; Young Leader; and Hall of Fame.

Wesfarmers Chemicals, Energy & Fertilisers (WesCEF) won the Net Zero Transition Award for its extensive emissions reduction initiatives in the organisation's Our Journey to Net Zero program.

WesCEF CEO Ian Hansen was also recognised for his outstanding contribution to the long-term success and sustainability of the Australian chemistry industry, and to Chemistry Australia, with his induction into the Hall of Fame.

The Circular Economy Award was presented to Dulux Paints and Coatings for its Dulux Project Earth Circular Plastic

Recycling Program, which has collected and recycled more than 25 tonnes of paint pails.

Air Liquide Australia, a supplier of gases, technologies and services for industry and health, won the Health, Safety and Environment Award. Air Liquide Australia's comprehensive Safety from Every Angle continuous improvement program has helped it achieve year-on-year injury reductions.

Finally, Incitec Pivot Limited's Hannah Campbell has been named the industry's Young Leader Award winner.

Hannah is a member of Chemistry Australia's Emerging Leaders program and the award recognises her significant achievements in team leadership roles in a production environment and inclusive approach to leadership.

Chemistry Australia CEO Samantha Read said, 'It's our first ever awards, and I'm pleased to say our judges had a very impressive field of nominees to choose from.'

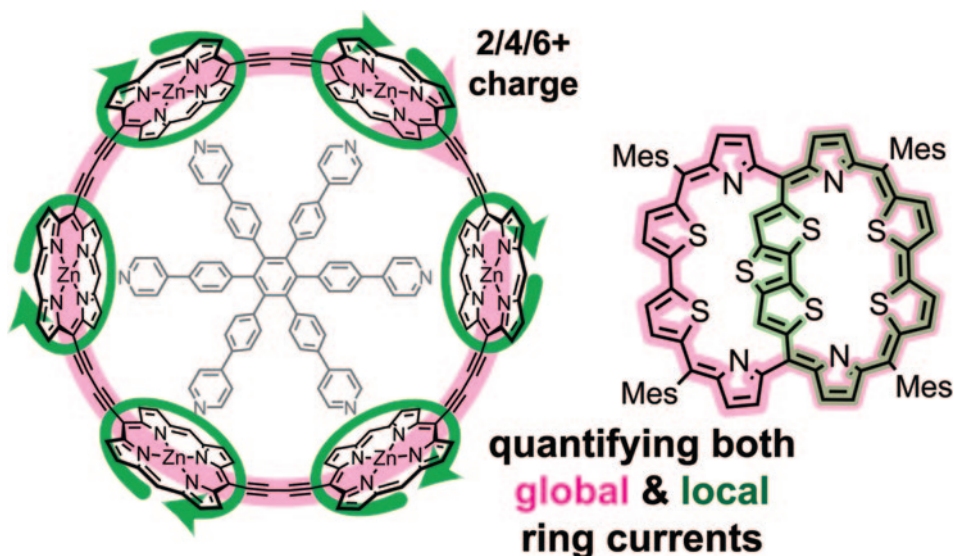
'The breadth of talent and ideas in the award nominations we received demonstrates there is considerable innovation currently taking place in our sector, particularly in the areas of climate neutrality and the circular economy.'

'Our congratulations go to everyone who participated in the awards, especially our finalists and award winners, who are making considerable advances for their organisation, the industry and for the future of Australia.'

Chemistry Australia

Unravelling aromaticity in complex conjugated molecules

Aromaticity is one of the most fundamental concepts in organic chemistry, yet it belies an exact definition. Most of us would agree that aromaticity relates to the delocalisation of electrons, and so further understanding aromaticity contributes to the design of new organic conductors. Many chemists will know – from their undergraduate days if not more recently – how NMR spectroscopy can be used to assign aromaticity, because the ‘ring current’ of circulating π -electrons predictably influences the chemical shifts of NMR peaks. But what if a molecule has multiple aromatic circuits? Could experimental NMR data be used to quantify the strength of the ring current (in nanoamps per tesla) passing through each different pathway? Researchers at the Universities of New South Wales, Oxford and Glasgow have developed a new method to do just this, revealing that macrocyclic π -conjugated molecules

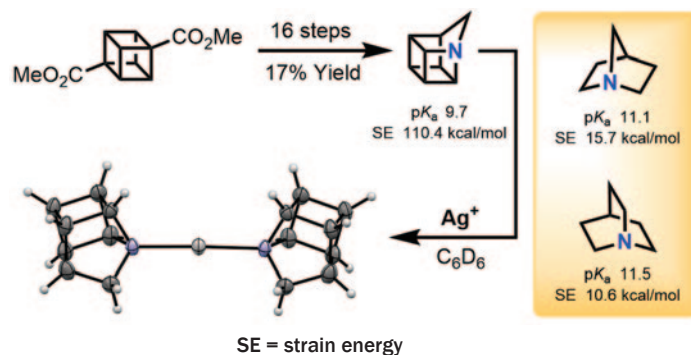


can sustain multiple measurable ring currents at the same time and that a molecule can perplexingly exhibit both aromatic and antiaromatic circuits simultaneously (Bradley D., Jirásek M., Anderson H.L., Peeks M.D. *Chem. Sci.*

2023, **14**, 1762–8). The results have implications for the design of ever larger π -conjugated molecules, and provide one of the few experimental yardsticks against which a molecule’s ‘degree of aromaticity’ can be measured.

Highly strained heterocyclic cage synthesised

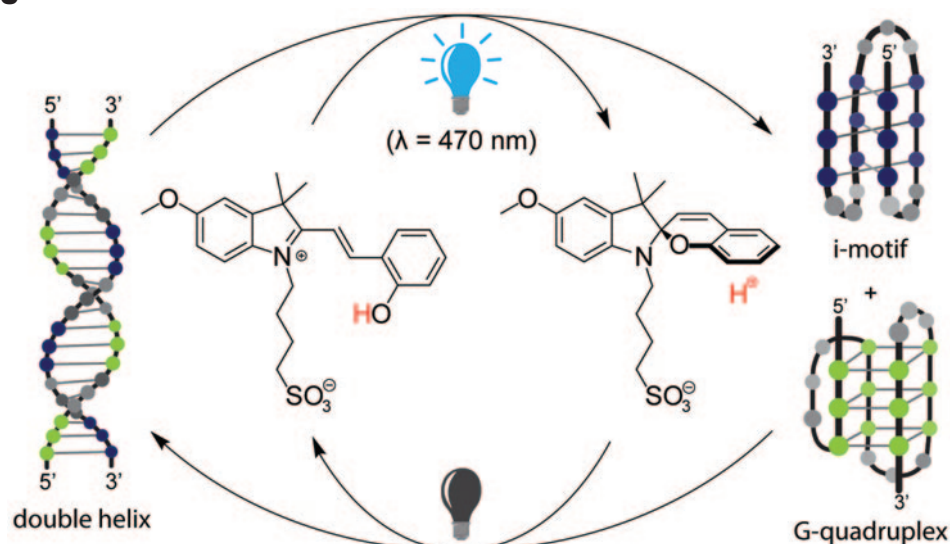
Almost six decades after the synthesis of homocubane, a team of researchers from the Universities of Queensland and Chicago, the Queensland University of Technology and CSIRO have successfully incorporated a nitrogen atom into the skeleton in synthesising 1-azahomocubane (Fahrenhorst-Jones T., Marshall D.L., Burns J.M., Pierens G.K., Hormann R.E., Fisher A.M., Bernhardt P.V., Blanksby S.J., Savage G.P., Eaton P.E., Williams C.M. *Chem. Sci.* 2023, **14**, 2821–5). Despite deviating significantly from ideal bond angles, the nitrogen atom tolerates the immense chemical strain remarkably well. Evaluation of the electronic and physical properties of 1-azahomocubane revealed the polycyclic cage amine to be over 20 times less basic than similar amines and to display only minor changes in overall geometry compared to its all-carbon counterpart (i.e. homocubane). The importance of strained molecules such as 1-azahomocubane lies not only in their ability to provide theoretical insights into chemical bonding,



but also in their unique properties and reactivity, which can be useful in a wide range of fields, including bioactive molecule discovery, materials science, and energetic materials. 1-Azahomocubane is a milestone among high-strain molecules and is a favourable sign for the development of other N-heterocyclic structures with even greater strain.

Shape-shifting DNA with light

DNA lies at the core of every biological system, most often in the form of a double helix. It can, however, adopt alternative three-dimensional conformations that fulfil regulatory functions such as in gene transcription. DNA's versatility, programmability and robustness are increasingly being used to design stimuli-responsive materials or nanoscale devices with functions including capture and release. A recent study by researchers at the University of New South Wales has shown how light may be used to change the 3D structure of short DNA strands (Wimberger L., Rizzuto F.J., Beves J.E. *J. Am. Chem. Soc.* 2023, **145**, 2088–92). Being able to control such structures with light allows high spatiotemporal resolution and avoids waste. The method used a small molecule, a photoacid, to reversibly control the pH, leading to the structural change of the DNA. This shape-shifting process was applied to several



unmodified DNA sequences of varying lengths and pH sensitivity. The recovery process after light irradiation and the species distribution could be tuned by adjusting the initial pH and by introducing a DNA binder. Using small

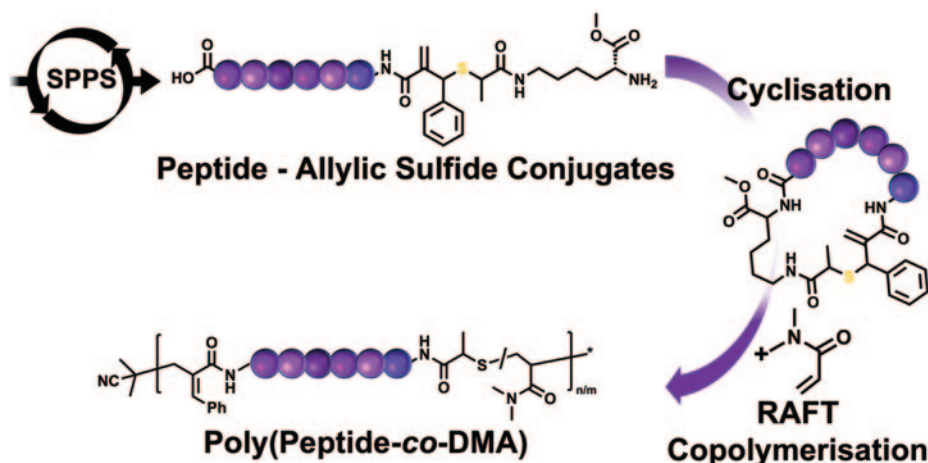
molecules to change the 3D conformation of DNA with light may advance the development of functional DNA devices and lead to more sophisticated light-responsive materials.

Embedding peptides into synthetic polymers by radical ring opening

Biopolymers such as proteins and nucleic acids are the key building blocks of life. Synthetic polymers have nevertheless revolutionised everyday life through their robust synthetic accessibility. Combining the unmatched functionality of biopolymers with the robustness of tailorable synthetic polymers enables the

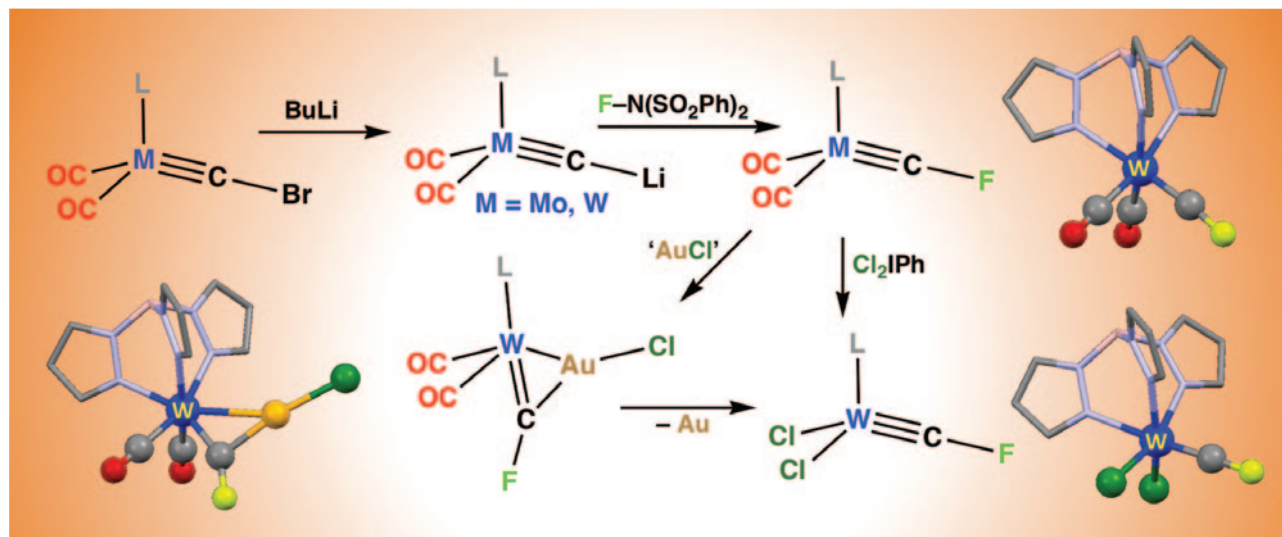
possibility to design new materials ad hoc for an array of applications, including catalysis and degradation. Combinations of natural polymers such as peptides with synthetic polymers are, however, limited to tethering peptides onto the side chains or chain ends of the latter. This synthetic limitation is a critical restraint,

considering that the function of biopolymers is programmed into the sequence of their main chain. Work at the Queensland University of Technology's Soft Matter Materials Laboratory led by ARC DECRA Fellow Hendrik Frisch and PhD student Federica Sbordone reports the radical copolymerisation of peptides and synthetic comonomers yielding synthetic polymers with defined peptide sequences embedded into their main chain (Sbordone F., Veskova J., Richardson B., Do P.T., Micallef A., Frisch H. *J. Am. Chem. Soc.* 2023, **145**, 6221–9). Key to this work is a solid-phase chemistry approach to synthesise peptide conjugates containing allylic sulfides that, following peptide cyclisation, can be readily copolymerised with *N,N*-dimethylacrylamide (DMA) controlled by reversible addition–fragmentation chain transfer (RAFT).



SPPS = solid-phase peptide synthesis

High oxidation-state fluorocarbynes

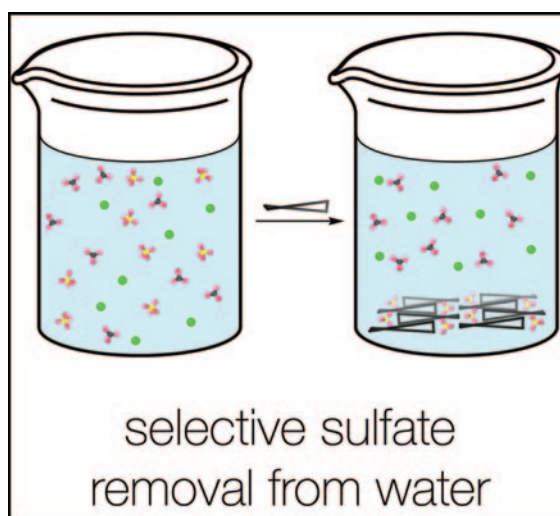


The making and breaking of carbon–fluorine bonds at a metal centre presents a topical challenge as ‘forever chemicals’ attract increasing environmental and health concerns. Fluorine is unique among the halogens because of its small size and unsurpassed electronegativity, meaning synthetic strategies appropriate to the heavier halogens do not necessarily translate to the *enfant terrible*. A new strategy has been developed by Richie Manzano and Anthony Hill at the Australian National University to access complexes of the smallest fluorocarbon: fluorocarbyne CF (Manzano R.A., Hill A.F. *Chem. Sci.* 2023, **14**, 3776–81). Highly reactive lithiocarbido complexes of tungsten

and molybdenum when treated with the electrophilic fluorinating agent $F-N(SO_2Ph)_2$ afford the remarkably stable fluorocarbynes $[M(=CF)(CO)_2(L)]$ ($M = Mo, W$; $L = \text{tris(dimethylpyrazolyl)borate}$). The tungsten complex is in turn oxidised by gold(I) chloride, via the first bimetallic fluorocarbyne, to ultimately provide the first isolable high oxidation-state (‘Schrock-type’) fluorocarbyne $[W(=CF)Cl_2(L)]$. Prior to this work, high oxidation-state fluorocarbynes had only been fleetingly observed from laser-ablated metal atoms condensed in argon matrices at 8 K.

Selectively sequestering sulfate

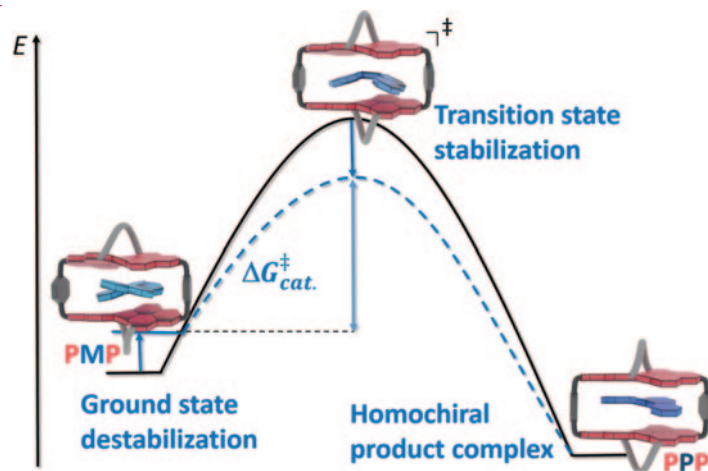
Anions are critically important in a range of biological, environmental and industrial processes. So selective recognition and sensing of these species is a longstanding goal in supramolecular chemistry. This is very difficult to achieve in water owing to its hydrogen bond donating and accepting capabilities. Traditionally, supramolecular chemists have built intricate 3D receptors containing numerous hydrogen bond donors to achieve selective recognition, but this remains very challenging. An alternative for some anions is to use a simple precipitant such as Ba^{2+} to precipitate the anion, although this approach tends to suffer from a lack of selectivity. A collaboration between the Jolliffe group at the University of Sydney and the White group at the Australian National University reports a simple readily prepared organic bis-amidinium compound that can precipitate sulfate from water (Tzioumis N.A., Cullen D.A., Jolliffe K.A., White N.G. *Angew. Chem. Int. Ed.* 2023, **62**, e202218360). The precipitant is simple to make, is highly selective and can be easily recycled



for re-use. It can remove more than 95% of sulfate from water and can even function in acidic conditions and in seawater, selectively precipitating sulfate from the complex mixture of species.

π - π catalysis with a twist

Enzymes actuate catalysis through transition state stabilisation and ground state destabilisation, inducing enantioselectivity through complex chiral pockets in their active sites. In a multinational collaboration between researchers from Universität Würzburg, the University of Western Australia, and the University of New England, Frank Würthner, Amir Karton and coworkers used experimental and computational approaches to develop a simple supramolecular model system that employs basic enzymatic catalysis principles to catalyse the enantiomerisation of [5]helicene (Weh M., Kroeger A.A., Shoyama K., Grüne M., Karton A., Würthner F. *Angew. Chem. Int. Ed.* 2023, **62**, e202301301). In their model, catalysis is mediated not through an elaborate network of functional groups but through π - π catalysis exerted from the curved aromatic framework of a chiral *para*-xylylene-linked perylene bisimide (PBI) cyclophane. According to energy decomposition analyses, the transition state stabilisation originates solely from dispersion and electrostatic interactions. Time-dependent circular dichroism studies revealed that the enantiomerisation kinetics of [5]helicene is accelerated by a factor of about 700 at room temperature. Detailed 2D NMR and crystallographic

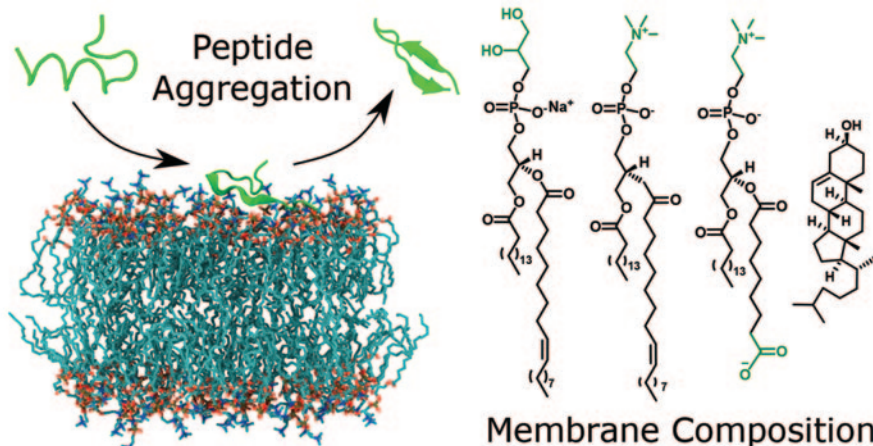


'P' and 'M' label the helicity ('plus' or 'minus') of the coloured molecular fragments.

studies confirmed the transfer of chiral information from host to guest. A comparison with the meso-congener of the catalytically active cyclophane showed that upon configurational inversion in one PBI moiety, chiral recognition and the catalytic effect are lost, highlighting the importance of precise transition structure recognition in supramolecular enzyme mimics.

Lipid oxidation drives peptide self-assembly near membranes

Peptides are essential biomolecules with myriad precise functions in both physiology and nature. However, one misfold can begin a cascade in which peptide self-assembly leads to the formation of amyloid, a structure that has implications in human neurodegenerative diseases such as Alzheimer's disease. Oxidative stress on a cellular scale plays a key role in the pathogenesis of Alzheimer's disease, resulting in chain reactions and unregulated lipid peroxidation that can cause serious damage to the cell membrane. A recent study by researchers in Australia and Germany has investigated the effect of lipid oxidation on the self-assembly behaviour of two peptides: the anionic A β_{40} peptide implicated in Alzheimer's disease and Uperin 3.5, a small cationic antimicrobial peptide secreted by the Australian toadlet *Uperoleia mjobergii* as part of its innate host defence (John T., Piantavigna S., Dealea T.J.A., Abel B.,



Re-used with permission from *Chemical Science*, <https://doi.org/10.1039/D3SC00159H>

Risselada H.J., Martin L.L. *Chem. Sci.* 2023, **14**, 3730–41). This research demonstrated both experimentally and computationally that membrane oxidation can alter the self-assembly properties, stemming from the change in membrane surface charge, and thus the initial electrostatic attraction between the

peptide and the membrane. These results enabled a model to be proposed that predicts how changes to a cell membrane composition could affect the self-assembly properties of any peptide. In turn, this work could assist in understanding amyloid aggregation.

Compiled by **David Huang** MRACI CChem (david.huang@adelaide.edu.au). This section showcases the very best research carried out primarily in Australia. RACI members whose recent work has been published in high-impact journals (e.g. *Nature*, *J. Am. Chem. Soc.*, *Angew. Chem. Int. Ed.*, *Chem. Sci.*) are encouraged to contribute general summaries, of no more than 200 words, and an image to David.

New way to teach students about nucleobase pairing

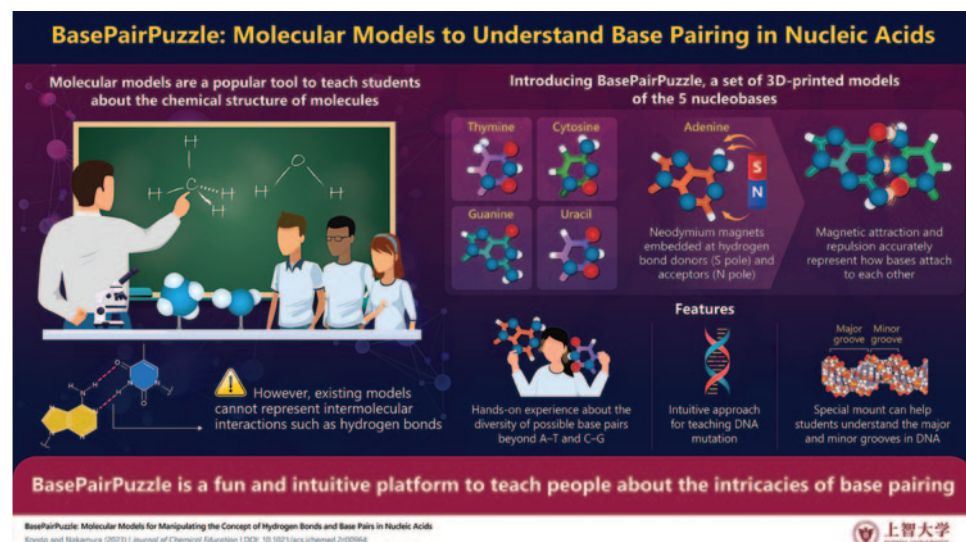
Molecular models can be a great tool to teach chemistry and biochemistry, but most of them cannot accurately depict intermolecular interactions, such as hydrogen bonds. In a recent study, researchers developed a 3D-printed molecular model called BasePairPuzzle, which uses embedded neodymium magnets to accurately mimic intermolecular interactions between the five nucleobases. This model provides an intuitive, hands-on experience to help students understand base pairing, as well as concepts such as DNA mutations and the double helix.

Molecular models are a tried-and-tested tool for teaching chemistry to students of all ages. By enabling users to visualise the three-dimensional structure of a molecule and how its atoms are arranged, they can accelerate the learning process for essential topics such as covalent bonds. In biochemistry classes, molecular models of DNA are a popular way to teach students about nucleobase pairing and how the iconic double-stranded helical structure looks.

Despite their usefulness, most molecular models in the market cannot represent intermolecular interactions. Because the strength of, for example, hydrogen bonds varies with distance and angle, the bonds are challenging to depict using conventional molecular models.

Hydrogen bonds are among the main driving forces behind base pairing in DNA and RNA, and it would be better for students if there was a molecular model that could represent them more accurately. In response to this challenge, Associate Professor Jiro Kondo from Sophia University and Mr Shota Nakamura from StudioMIDAS, both in Japan, designed BasePairPuzzle, a new type of DNA molecular model that accurately represents base pairing. The details and uses of this model have been published in the *Journal of Chemical Education* (doi.org/10.1021/acs.jchemed.2c00964).

At first sight, the pieces of BasePairPuzzle appear to be simple representations of the nucleobases



A novel 3D-printed molecular model of the five nucleobases uses embedded magnets to accurately represent intermolecular interactions.

adenine, cytosine, guanine, thymine and uracil. However, these 3D-printed parts have strategically placed crannies that can fit commercial cylindrical neodymium magnets. The idea is that the repulsive and attractive forces between these magnets accurately mimic the hydrogen bonds and electrostatic forces that naturally exist between nucleobase pairs.

Thanks to its ingenious design, BasePairPuzzle allows students to not just see but also feel how nucleobases pair with each other. 'By designing the shape and size of the pieces to fit in the palm of the user's hands, the right amount of magnetic force, and the clicking sound when hydrogen bonds are formed, the user can comfortably experience the sensation of molecules interacting with each other', highlighted Kondo.

While the puzzle is great for understanding why the complementary A-T and C-G pairs are by far the most common, it has the added benefit of allowing for non-complementary pairs to form. In turn, this makes it clear to students that there is great diversity in nucleobase pairs beyond the complementary ones, and that this diversity is what gives rise to the varied DNA and RNA structures that we now know exist. In this regard, Kondo

explained, 'Once the students realise that the pieces are attracted to each other by magnetic forces, they will understand that any combination of the four bases will stick together in some way. The important thing to remember is that all of the combinations of bases the students make, even triplets and quartets, can exist in some RNA structures in living organisms, which means they are all correct'.

BasePairPuzzle pieces can be mounted onto a special cylindrical mount to hold complementary base pairs and replicate the double-stranded helical structure of DNA. This lets students easily visualise the difference between the major and minor grooves. Another use for BasePairPuzzle is to illustrate how DNA mutations occur as an intuitive step-by-step process.

Kondo has already given many lectures and classes using BasePairPuzzle in both high school and university and has received lots of positive feedback from students. Moreover, the researchers have made the necessary files for 3D printing BasePairPuzzle pieces available to everyone free of charge, hoping to provide a hands-on experience of nucleobase pairing to as many students as possible.

Sophia University

A mixed waste plastic composite made from polyethylene, polypropylene and polymethylmethacrylate after testing.

Kiyah De-Arne



Construction and deconstruction

Transitioning to ‘no waste’ can be a complex task, so University of Southern Queensland researchers at the SIMPLE hub and NO WASTE pilot precinct are aiming for simple design, processes and recovery to keep ‘waste’ out of landfill.

Materials and substances from ‘waste’

One of the advantages of working in a multidisciplinary team is that the combination of expertise can help accelerate tackling broad and complex problems such as how to prevent ‘waste’ material from having a detrimental environment impact. There is value in acknowledging that there is no such thing as waste, just a material that has not found a ‘home’ or follow-on use yet.

With ‘value’ being the key word, the current focus in the waste material research space has not only been on the technical approaches for transforming product manufacture, but has also been on their viability (e.g. financial and ease of implementation). This is because viability of the solution is key to uptake into common practice. In a circular economy, the ways in which we design how to construct and deconstruct products both physically and

chemically so that they are re-usable, be it through recycling, remanufacture, repair or refurbishment.

With this purpose, our team, consisting of a wide variety of engineers, scientists, and education and business academics focuses on transforming product manufacture and supply chains to be sustainable. The industry sectors of focus for our work include the food, medical, construction, resource and energy sectors. At times, the collaboration of these industries is one strategy to prevent 'waste' from going to landfill. The technical approaches vary for each sector but focus on the development of processes that are not overly complicated, are potentially easy to implement and have low energy intensity. The other area of focus is design of products that are easy to construct and deconstruct, to make recovery of separate material streams easier as many products are what we might term 'composite materials'.

Here we showcase a series of work carried out under our team's major funded programs supported by the Australian Department of Education's Strategic University Reform Fund and their Regional Research Collaboration scheme. These programs are the New Options for Waste and Saving The

Environment (NO WASTE) pilot precinct and the Sustainable Industry Manufacturing Planning for Long-term Ecosystems (SIMPLE) hub, led out of the University of Southern Queensland in Toowoomba.

A touch of glass

In Australia, we use approximately 1.3 megatonnes of glass each year. The composition of the glass types used can vary, complicating their recycling if we have mixed glass streams. Many people are familiar with bottle glass and many of the recycling schemes that have been implemented nationally and are growing due to the inherent ability of glass to be recycled multiple times. However, in the movement of collected glass bottles to recycling, there are some issues with glass mixing, fines generated where cullet (scraps of broken or waste glass gathered for remelting) is required and contamination leaving some material still to be utilised. In addition, the issue of other types of glasses from other sources, such as solar panels, automotive glass and construction glass, still needs to be resolved because of the glass composition and the composite nature of these products (containing items other than glass).

Our team's recent work has shown that brown, green and clear glass

perform differently from each other in applications such as concrete and grout, affecting the behaviour of water and its required amount in a mix formulation. One of the challenges of use in these applications is that although there has been a lot of work in this space and adoption in some industry applications, the longevity of these products still needs further examination due to potential alkali silica reaction of cement with the glass (see bit.ly/3mZF0xQ for reaction details), commonly known as concrete cancer, that could be detrimental to structural integrity. Our team has focused on some prevention strategies including:

- coating the glass particles with other 'waste' materials, including different plastics, thereby dealing with two waste streams at once
- some novel process intensification combining cleaning and milling steps to accelerate size reduction and prevent alkali silica reaction through this approach.

Such a card

Although we have had a long history of recycling cardboard and paper in Australia, there are a limited number of times this can be done before structural integrity is affected. Another complication is that many paperboard

Green glass mortar bar samples

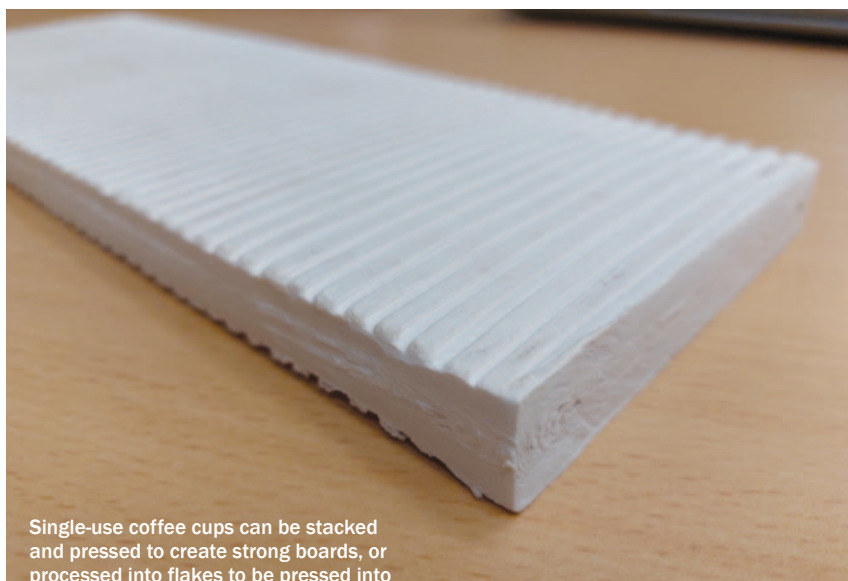
Eric Song



and cardboard products may be coated, typically with a polymeric coating, sometimes a wax, which means that they cannot be recycled with the usual cardboard and paper recycling streams. These may be in the form of items such as the humble cardboard box or coffee cup. There is much change occurring in how we may use the takeaway coffee cup in future – whether it remains as a coated paperboard or as a keep cup type alternative, there are challenges to be overcome. Until full bans on single-use coffee cups are implemented more widely, there is a problem of an

estimated 1 billion single-use coffee cups being used in Australia every year – that's a lotta lattes! But did you know that we can use the inherent composite nature of the humble single-use coffee cup to make products potentially as strong as MDF (medium density fibreboard)? The mechanical properties of such a product can be tailored by controlling the amount of coated interfacial area in contact in pressed 'cup-board' as shown in the images, which had polyethylene coating. This can be controlled through the size reduction of the cups from none

... we can use the inherent composite nature of the humble single-use coffee cup to make products potentially as strong as MDF ...



Single-use coffee cups can be stacked and pressed to create strong boards, or processed into flakes to be pressed into panels and other forms.

Matt Flynn



(just pressing stacked cups) through to finely milled cups, creating a compressible fluffy fibre.

Food for thought

As part of the team's work, some of the research focus is on materials and products derived from sustainable natural sources. One area of the team's work concentrates on extraction of 'molecules of interest' from food excess and by-products and refinement into useful and high-value products, which we have described previously. Some of the materials and substances of interest include structuring molecules, typically pectin and cellulose biopolymers, which can be used for development of novel films, hydrogels and structured particles to fit a range of applications, and smaller micronutrient molecules with potentially useful biological functions.

One of the first challenges of extracting these substances is ensuring that the raw material feedstock is appropriately preserved with suitable resource use. Some approaches can be energy intensive, particularly drying approaches, but naturally sourced preservatives can assist in shelf-life extension until processing can occur. Some of our team's work has focused on the use of anthocyanin from excess food sources as a useful molecule to aid healing and as a biosensor to indicate wound pH



Aloe-alginate hydrogels incorporating lemon myrtle oil.

Dinuki Seneviratne

and health status, thereby having a two-pronged therapeutic function without being too high tech or expensive. This makes it ideal for applications in rural, regional or remote areas where health resourcing can be limited. We have also developed a rapid analysis technique and colour correlation to track fresh fruit anthocyanin development to help pinpoint the optimal harvest point for maximum anthocyanin content. This has the opportunity to optimise the value of the fruit and the products it can be transformed into, which may have high-value applications in cosmetics or health.

Some of our team's work has focused on the use of anthocyanin from excess food sources as a useful molecule to aid healing and as a biosensor to indicate wound pH and health status ...



A stretched orange hydrogel.

Nils Priesler

Golden opportunity

Citrus fruits are a great source of not only useful micronutrients but also structural biopolymers such as pectins and celluloses. In juicing applications, these are often lost through discard of the pomace by-product (the pulp left behind after juicing). Again, one of the challenges is the timely preservation of this material to prevent excessive microbial load before it can be used, with high-volume juicing manufacturing producing several tonnes of this material. One of our projects with this very useful material focused on developing a range of products through a series of (confidential) process steps including pectin-based hydrogels and a liquid-extracted 'syrup' useful for fermentation into novel cellulosic materials. The focus was on uncomplicated processing approaches to achieve these outcomes. As a result, the 'syrup' will now form the basis of a future project extending the structured cellulose formation from 'waste'. This is advantageous because it lowers the cost of producing these types of products by fermentation techniques if

Mixed plastic bar wrapped in a waste material fibre composite.

Geoff Germon



Many of the issues lie with single-use items and those that end up in commingled recovery streams requiring many steps such as sorting, cleaning and pre-processing ...

the feedstock is produced from this by-product. The feedstock source will also influence the subsequent material properties including strength, colour and porosity helping tailor them for a range of applications. Cellulose is very versatile; not only is it useful for making paper but it can also be used for higher-tech applications such as batteries and acoustic materials.

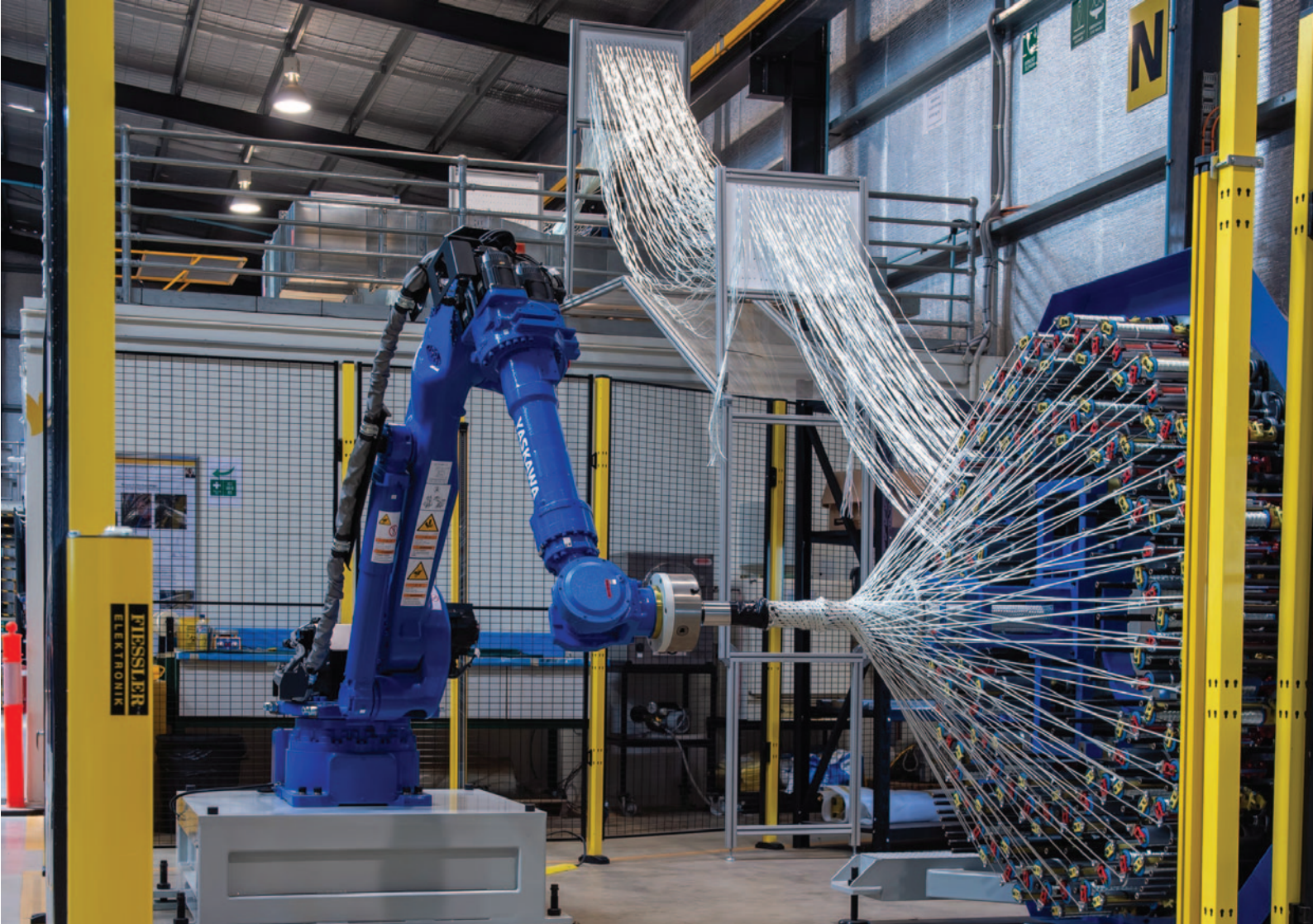
Plastic fantastic

We carry out a range of work focused on preventing plastic waste, which in

some instances is considered not only an environmental issue but also a health one (e.g. microplastics). Plastic has become ubiquitous for many applications such as packaging, PPE, electronics and automotive. Many of the issues lie with single-use items and those that end up in commingled recovery streams requiring many steps such as sorting, cleaning and pre-processing before they can be used in typical plastic manufacturing processes.

With our industry partner, Talon

Technology, we have been turning that on its head by utilising the inherent nature of plastic mixtures to create products that contain more than 95% mixed waste. Effectively, these are all plastic composites with a low melting point polymer matrix, incorporating higher melting point reinforcement. Similar to the coated cardboard and paperboard examples, the integrity and strength of these materials rely on controlling the size of the interfacial surfaces in contact and the strength of the bonds that form. These have shown to have significant mechanical performance, excess to product requirements for certain applications. One of the challenges is to then change perceptions of how this may compare to a single pure material product performing the same function with a narrower band of performance or tolerance. Another consideration is how this may change how we approach product standards.



T4L dual-ring robotic braiding cell for making advanced fibre composite shapes.

Centre for Future Materials, University of Southern Queensland

The near future

Some of our team have worked on fibre composite design and advanced manufacturing. These materials can be used for a range of applications including automotive, aerospace, marine, infrastructure and energy applications (e.g. wind turbines). Several strategies are being developed globally to deal with end-of-life fibre composites that include their use in other products, as well as some clever chemistry design to recover either the resin component or the fibre component. Because of the growing volume of fibre composite items that will end their service life, tackling this problem at scale is necessary. Our team will be focusing

on tailored approaches to recover both resin and fibre appropriately.

Technology is impactful, behaviour change more so. As part of our research program, as well as the technical research, we have a broad-reaching education stream targeting everyone from prep age upwards on how we can transition from discarding materials to transforming them into useful items. This helps in the co-design of solutions so that potential users may feel more ownership. The focus is on strategies that are uncomplicated, financially viable, and able to be implemented and designed as fit for the geographical environment in which they are located (be it regional or metropolitan).

The opportunity to transition from linear pathways for material to more circular or 'loopy' pathways is significant and the benefits are broad. Through collaboration in this fascinating chemical and materials space we can progress towards 'no waste'.

Paulomi (Polly) Burey, Jessica Feldman, Hannah Seligmann, Eric Song, Matthew Flynn, Andreas Helwig Zahra Gharineiat, Dinuki Seneviratne, Eliza Whiteside, Tristan Shelley, Nils Priestler, Allan Manalo, Ali Mirzaghorbanali, Hadi Nourizadeh, Michael Roberts, Rose Nicol, Petrea Redmond, Mark Lynch, John Dearnaley, Kiyah De-Arne and Geoff German (Talon Technology) are part of the NO WASTE pilot precinct and SIMPLE Hub, University of Southern Queensland, Toowoomba. A reference list is available from the authors (NOWASTE@usq.edu.au).

Advancing our transition to a greener plastics future



The Andrew N. Liveris Building at the University of Queensland's St Lucia campus, home of the School of Chemical Engineering. University of Queensland

BY STEVEN PRATT

At the ARC Industrial Transformation Training Centre for Bioplastics and Biocomposites, PhD candidates and early career researchers are addressing the wicked problem of plastics waste.

Plastics are everywhere. They are strong, durable, lightweight, easily formable – and cheap. Modern society could not function without them. However, our success at engineering such useful materials has created a systemic problem, with more than 10 megatonnes of plastic leaking to the environment and into the oceans annually. The problem is so pronounced that researchers at the Stockholm Resilience Centre are considering it as a planetary boundary threat.

Biodegradable bioplastics, along with their natural fibre composites, are seen as pivotal for a transition to a more sustainable plastics economy. The opportunity for Australia is very large: while the bioplastics and biocomposites industry in Australia is still emerging, Australia has an abundance of the requisite natural bioresource raw materials for the manufacture of bioplastics and biocomposites. A new \$13 million

Australian Research Council (ARC) Industrial Transformation Training Centre for Bioplastics and Biocomposites, based at the University of Queensland's School of Chemical Engineering, has been established to advance the transition. The training centre is a partnership between the University of Queensland and QUT, alongside the Queensland Government, Kimberly-Clark Australia, Plantic Technologies, Australian Packaging Covenant Organisation, Minderoo Foundation and the City of Gold Coast.

The Centre supports the training and development of 19 PhD candidates, along with four early career researchers. Much of the research focuses on product development. It has been estimated that biodegradable, bioderived plastics could directly substitute for nearly a third of petroleum-based polymers. Biodegradable plastics and some composites are already widely used in disposable items such as

packaging, containers, straws, bags and bottles. Packaging, particularly thin films, represents more than 50% of the global plastics market, and there is a serious issue with contaminated films that cannot be effectively recycled and are sent to landfill or escape into our environment. Therefore, one of the key areas of global interest is in the development of flexible films for packaging that are truly biodegradable under ambient conditions, opening the door to a wide range of waste management options, including digestion for biogas production.

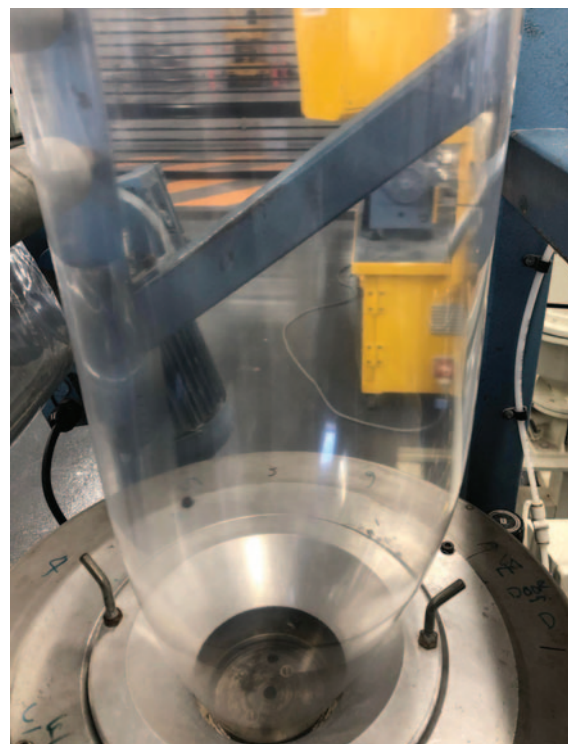
The copolymer polyhydroxybutyrate-valerate (PHBV), which is the most widely commercially available biopolymer in the polyhydroxyalkanoate (PHA) family, is an excellent candidate for such applications. PHAs have high water barrier properties along with reasonable gas barrier properties, which together help extend shelf life of packaged products. And, above all, PHAs are truly biodegradable in ambient conditions; other plastics currently used to make thin films either don't biodegrade or only biodegrade under a limited set of conditions. But PHBV has an extremely low melt strength and is very challenging to film blow and thermoform due to its flow performance characteristics; it undergoes strain thinning during extensional flow. This is suspected to be due to a lack of entanglements that PHBV exhibits in the melt. In particular, the low melt strength of PHBV limits its applications to products that are produced by processing methods such as extrusion, which produce thin strands or thick sheets, and injection moulding, which can produce products like meat trays or punnets.

Enter PhD candidate Sam Lawless. In Sam's PhD project he has modified PHBV to facilitate strain hardening, making it amenable to film blowing. He has already used the modified polymer to blow films as thin as about

40 micrometres, which is the desired thickness for plastic films in many film applications. This new PHA formulation increases the suite of potential commercial products that can be made from bioderived and truly biodegradable plastic. But still more work is to be done to now improve the mechanical properties, particularly the toughness, of the PHA films. Sam is now teaming up with Dr Katrin Kockler and two new PhD candidates to tackle this problem.

One of the Centre's industry partners, Plantic Technologies, is an international innovator in starch-based barrier materials, offering a wide range of bioplastic packaging (principally used for thermoformed packaging, films and pouches) derived from starch, as an alternative to conventional plastics packaging. This innovative material, developed initially in partnership with the University of Queensland, CSIRO and other institutions, has positioned Plantic as a global leader in the field. Professor Pete Halley and Dr Emilie Gauthier are now leading research to understand and improve the key processing and physical properties of the starch-based films as well as investigating other packaging applications. This work focuses on the development of technologies to address the challenge of producing high-performing thin films, while maintaining the barrier performance of this 100% biodegradable starch-based sheet, given that the high oxygen barrier is crucial for multilayer food packaging applications to extend shelf life. This will in turn reduce food waste, helping to reduce the greenhouse gas emission through materials supply, processing and end-of-life options.

Beyond packaging, there is significant opportunity for immediate application of bioplastics and biocomposites in environments where collection and recycling of products is near impossible (e.g. agricultural applications, where biodegradable mulch films and encapsulants or



Film blowing the commercially available biopolymer polyhydroxybutyrate-valerate (PHBV).



PhD candidate Sam Lawless with modified PHBV for film blowing.

coatings for fertilisers and other agrichemicals that are truly biodegradable in on-farm soil environments would not have to be removed and disposed). An advantage offered by biodegradable polymers is the opportunity to control the release of bioactives without leaving unwanted, non-degradable residues. But tight economic margins for products such as fertilisers limit the maximum polymer content of controlled formulations to <10 wt%. Achieving sustained, long-term release profiles is then challenging when utilising thin, naturally biodegradable polymer coatings. Further, water ingress leads to granule swelling, so significant polymer elongation is required to avoid rupture. Dr Ian Levett is building in-house coating equipment for spray coating of fertiliser granules in order to investigate release profiles from a suite of biodegradable polymer-coated fertilisers. In parallel, he is developing mathematical release models, accounting for diffusion processes, granule swelling and polymer degradation to guide materials selection and tailor formulation design. A newly joined PhD candidate, Sumedha Amaraweera, will build on developments in this space.

But the Centre is not only focused on overcoming technical challenges. Plastic pollution is a wicked problem, meaning the Centre must perform leading-edge research

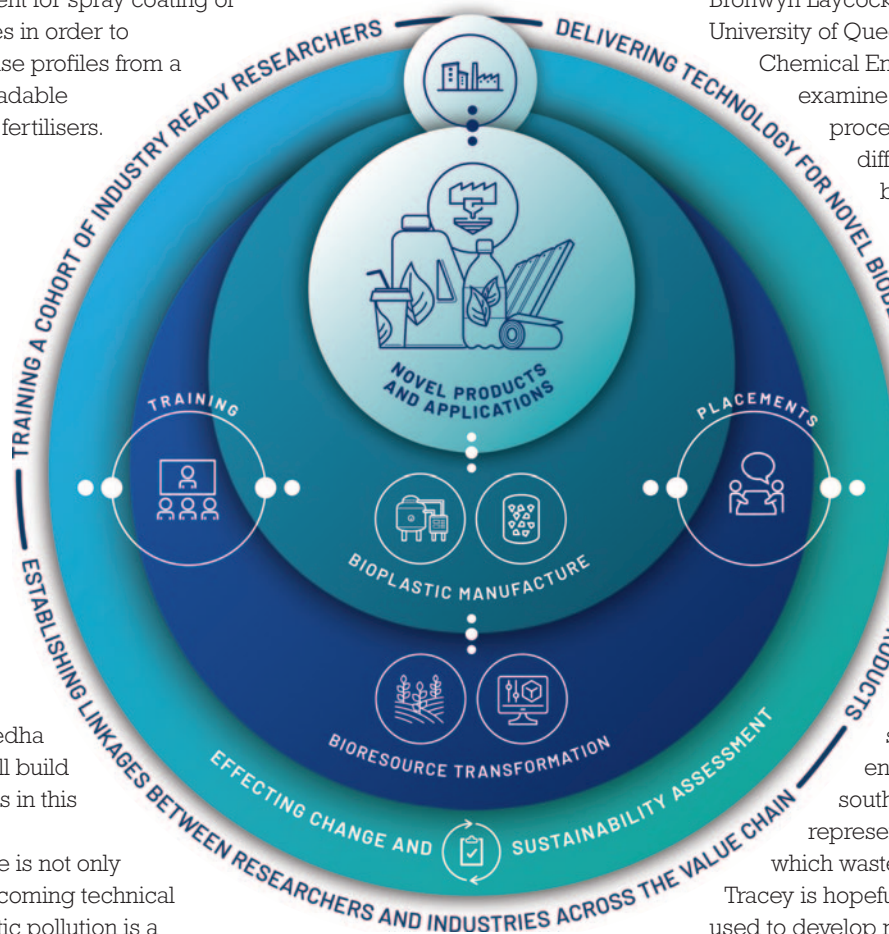
on product development but with a holistic focus. So, in addition to core polymers/materials expertise, the Centre pulls together experts from across the biomaterials value chain, recognising the critical importance of social, economic and environmental issues in delivering a viable transition strategy. Research theme 1 will deliver advances in technology for bioresource transformation, including detailed understanding of the opportunities afforded to supply chain integration. Research theme 2 considers bioplastic manufacture, including addressing engineering constraints associated with scale-up of technology. Coupled with this, a clear objective is to utilise new and readily available bioplastics and biocomposites in the development of

novel products and applications (research theme 3). These activities are all underpinned by research into effecting change and sustainability assessment, which will lead to a better understanding of in-use and post-use stability and lifetimes, technoeconomic and life cycle assessments of these alternative products, and strategies for addressing social and policy barriers to their implementation (research theme 4).

For example, PhD candidate Tracey Read is studying what happens when these so-called 'greener alternatives' end up in waterways. Tracey says, 'We know most people think all biodegradable plastic is fast at biodegrading in any environment, but that is unfortunately not the case'.

Tracey is working with Professors Bronwyn Laycock and Paul Lant in the University of Queensland's School of Chemical Engineering, to examine how form and processing of three different types of biodegradable plastic (PHA along with polylactic acid (PLA) and polybutylene adipate terephthalate (PBAT)), commonly found in everyday packaging and waste bags, break down once in the water. The bioplastic samples have been submerged at aquatic environments across south-east Queensland, representing the locations to which waste plastics often travel.

Tracey is hopeful the research will be used to develop materials and products with reduced lifetimes and risk to marine life in the event the



The four research themes of the ARC Training Centre for Bioplastics and Biocomposites.

Bioplastics have exciting potential as an alternative to fossil-fuel-based plastics but, as with most new technologies, social acceptance and trust are fundamental to their widespread acceptance.

biodegradable plastic ends up in waterways. 'There is a lot of research on what happens to biodegradable plastic in soil, compost, on land, and in landfills, but we actually don't know what happens when these materials enter the marine environment', Tracey says. The project has been dubbed the 'Epic Field Trial'. You can follow along by searching @EpicFieldTrial on Instagram.

PhD candidate Hannah Bennett, who has just joined the Centre, is looking at bioplastics and responsible innovation. Bioplastics have exciting potential as an alternative to fossil-fuel-based plastics but, as with most new technologies, social acceptance and trust are fundamental to their widespread acceptance. It is important to identify public concerns, expectations and perceptions in order to support the responsible development of this technology. Hannah – under the supervision of Dr Severine van Bommel, Professor Emeritus Helen Ross (social scientists in the University of Queensland's School of Agriculture and Food Science) and Dr Anya Phelan (with the university's Business School) – recognises a wide range of



Tracey Read with her field trial rig containing a range of bioplastics processed in various ways.

possibilities in this subject area, but, given Hannah's background in sociology, cultural theory and design, is focused on the field of packaging. Hannah is excited by the connections with industry the centre offers, including a lengthy industry placement. Hannah says 'Transitioning to bioplastics involves more than just lab-based materials engineering. Plastics (both fossil- and bio-derived) exist within complex systems of stakeholders and user behaviours. Only by considering these systems can we create bioplastics that function as intended within the complexities of real-world use. My role within the centre is to examine these systems and find bottlenecks that may hinder the mainstream adoption, proper integration, and sustainable development of bioplastics'.

The plastics system is indeed complex, with a wide range of

stakeholders. It is hoped that by teaming material scientists and engineers with business experts, biologists and social scientists, the Centre can perform the leading-edge research with a holistic focus that's necessary to underpin Australia's transition to a globally significant player in the rapidly growing bioplastics and biocomposites industry.

Associate Professor Steven Pratt is Director, Centre for Bioplastics, School of Chemical Engineering, the University of Queensland.

New Fellows



Eveline Baker is a highly motivated scientist, her enduring and inspiring achievements earning dual recognition as RACI Fellow and Honorary Life Member. Her foundational research experience in coordination chemistry has translated to a divergent career.

In the pharmaceutical manufacturing industry, Eveline held progressive responsible positions. Two examples of TGA-approved therapeutic substances for which she prepared substantial submissions are Vicryl™, Australia's first synthetic absorbable suture, and a new anthelmintic

placed on the WHO essential medicine list, both still widely used 50 years later. Her board position, management experience, responsibility for quality systems, and in-process and laboratory operations are similarly applicable.

In academic education and government-based extensive industry training, her ability to understand individual learning needs is exceptional. Eveline has influenced thousands, from postgraduates to trainees, in positions such as director, auditor, researcher, manager, analyst, those daunted or struggling or mentored by her. Her approach to explaining concepts in her extensive subject menu, including practical, theoretical and management skills, has opened new horizons for many. Formalising her educational experience by postgraduate study, Eveline was awarded her second medal (via University of Technology Sydney) (the first being for Honours (University of Sydney)).

Particularly important for analytical chemistry is Eveline's specialist work on measurement uncertainty and validation in metrology (National Measurement Institute). At RACI conferences, she facilitated an understanding of measurands in laboratory analysis by referring to the rare Transit of Venus in 2004. In her Nyholm lectures, she featured chemistry using astronomical comparisons and music.

On the RACI NSW Contractors & Consultants Committee with chemical engineer husband John, her contributions, including presentation skills session, were well received. As honorary secretary general and vice president in similar bodies and as human resources coordinator for 4000 staff, she could promote the importance of chemistry.

Music performance is another part of Eveline's life, with achievement of AMusA following an invitation to be the solo performer, age 13, for the ABC. Her services over several decades via planning and playing music are widely appreciated.

Her interest in molecular properties, including biodegradability and safety, extends to materials, such as construction and fabric. Such knowledge allows responsible decisions for appropriate use.

Eveline worked with her husband in their environmental

engineering and scientific practice until his retirement. She especially values her family with a deep sense of commitment, dedication and responsibility, standards she has also applied in the workplace through her career.

Markus Müllner is currently an associate professor, an Australian Research Council Future Fellow, and the Associate Head of School (Research) in the School of Chemistry at the University of Sydney. Markus grew up in Germany and studied polymer and colloid chemistry at the University of Bayreuth, where he also received his PhD in polymer chemistry under the supervision of Professor Axel H.E. Müller.

Markus then moved to Australia to take up a McKenzie Postdoctoral Fellowship within Professor Frank Caruso's laboratory at the University of Melbourne. In 2015, Markus started the Polymer Nanostructures Group within the Key Centre for Polymers and Colloids after joining the University of Sydney in 2015.

Markus leads an interdisciplinary research program spanning polymer synthesis, photocatalysis, nanomedicine and battery applications. His group is particularly experienced in the synthesis and application of highly branched, bottlebrush-like polymers. He has won several awards for his research, including the 2021 Rennie Memorial Medal. He serves on the international advisory boards for leading journals in his field, such as *Polymer Chemistry* and *Macromolecular Rapid Communications*.

Markus has been an RACI member since 2013. He has regularly attended and in recent years also co-organised the Australasian Polymer Symposium. From 2019 to 2022, he was the Chair of the RACI New South Wales Polymer Group. Under his leadership, the group has hosted regular and well-attended events, especially symposia that facilitated networking and a sense of community for New South Wales polymer researchers. Markus also is an active member of the Steering Committee for the Australasian Polymer Summer School, which he co-hosted at the University of Sydney in 2019.



Vale Donald W. Watts AM

A mover and shaker

When Don Watts joined the University of Western Australia (UWA) Chemistry Department in 1962, his enthusiasm for chemistry and his passion for life enlivened the whole department. They similarly enlivened all his many and varied activities.

Donald Walter Watts was born in Perth on 1 April 1934 and died in Perth on 23 May 2022. He was educated at Hale School and the UWA, graduating with BSc(Hons) (1955) and PhD (1959) in physical and inorganic chemistry, and supervised by N.S. Bayliss. He worked as a postdoctoral fellow at University College London from 1959 to 1961 and was a visiting scientist at the University of Southern California (1967–8), ANU (1973) and the University of Toronto (1974). Don was promoted to reader/associate professor in 1969 and had a personal chair in physical and inorganic chemistry at UWA from 1977 to 1979.

His early research conducted with N.S. Bayliss was on the solution chemistry of nitrogen oxanions. Most of his subsequent work concentrated on various kinetic and equilibrium studies of coordination compounds in protic and dipolar aprotic solvents. He was awarded the 1966 Rennie Memorial Medal for this work. He became a Fellow of RACI in 1967 and was President of the Western Australian Branch in 1978–79.

Don was among the first to regard the fashionable CHEMSTUDY program of the 1960s as overly theoretical and unsuited to school curricula. He was the driving force behind the compilation of a mini encyclopaedia of industrial and everyday chemistry that was mandated for use in Western Australian schools – aptly entitled *Chemical properties and reactions: a basis for the study of chemical principles* (A.R.H. Cole, D.W. Watts, R.B. Bucat, 1977). In collaboration with N.S. Bayliss, Don toured all states of Australia to survey high-school chemistry courses. Following this, he produced a comprehensive report for the Australian Academy of Science entitled ‘Chemistry for Australian secondary school students – a recommended course of study’ (1979). In response to this report, the Australian Academy of Science committed to a mammoth writing project that led to the publication *Elements of chemistry: earth, air, fire and water* (editor R.B. Bucat 1984).

Don left academic chemistry in 1980 to become the Director of the (then) Western Australian Institute of Technology (WAIT). His leadership transformed the institute so that it was granted university status in 1986. Don was the foundation vice-chancellor of Curtin University of Technology (now Curtin University).

While at WAIT/Curtin, Don made significant contributions to Australian science and education policy. He was a member of the Australian Science and Technology Council (ASTEC) from 1984 to 1990. ASTEC was a Commonwealth agency that, between 1977 and 1987, advised the government on science and technology policy. In 1985, the government asked ASTEC to undertake a review of public investment in research and

development. Don was very much involved in the ASTEC report on the ‘Future directions for CSIRO’. This report recommended sweeping changes in the management of CSIRO, which the government implemented. For his service to the profession in its broadest sense, he was awarded the RACI 1987 Leighton Memorial Medal.

In 1987, he became the foundation vice-chancellor of Bond University, Australia’s 21st and only private university. Bond University was a joint venture between Alan Bond and the Bond Corporation and Mr Harunori Takahashi of the Japanese-based Electronics and Industrial Enterprises International. Don Watts, with his distinguished academic record and his practical and entrepreneurial approach to education, was the ideal person to be their foundation vice-chancellor. The university commenced teaching in 1989 with 322 students. He told the Bond student magazine, *The Arch*, in 2009 that he took the job because it was ‘absolutely vital’ there was an alternative to public university education in Australia. ‘I felt the overbearing bureaucracy in public education needed to be shaken by the existence of a private alternative’. Financial troubles with both the Bond Corporation and Electronics and Industrial Enterprises International led Don to depart from Bond in 1990. The current vice-chancellor of Bond, Tim Brailsford, has said that Don’s contribution to the university was ‘immense and unparalleled’.

After Bond, Don went to Darwin as the chief executive officer of the troubled Trade Development Zone Authority. He extricated the Northern Territory Government from possible disaster and stayed on in Darwin as the chairman of the Northern Territory Employment and Training Authority.

Don returned to Perth in 1995 and was a senior policy adviser to the vice-chancellor of the University of Notre Dame Australia.

In 1998, he became a Member of the Order of Australia, ‘For service to the advancement of science in the field of chemistry, to tertiary education, and to policy development in education’.

Don was an outstanding sportsman, representing Western Australia in both tennis and squash. He is survived by his wife Michelle and their two sons.

Education, science and technology in Australia have benefitted from his high profile and enthusiasm.



University of Western Australia Historical Society

R.B. Bucat FRACI CChem, G.S. Chandler FRACI CChem and
T.H. Spurling FRACI CChem

Inaugural Australian Rare Earth Chemistry Meeting



The Inaugural Australian Rare Earth Chemistry Meeting (OZRE2023), held at the School of Chemistry, University of Melbourne, on 10 February, was a recognition of the widespread current research activity in rare earth chemistry allied to the importance of rare earth chemistry to the extraction, processing and downstream applications of rare earth metals. These factors are germane to the fact that Australia has abundant rare earth resources, sufficient to be a major player internationally and a counterweight to the current Chinese domination of the field. The meeting could be regarded as being prescient of the ARC economic accelerator grants that have just been announced, as they include rare earth processing among the favoured areas. An important objective of the conference was to raise awareness of what the various groups are doing, so

that collaboration and mutual assistance become possible.

The conference brought together most of the rare earth chemistry research groups active in Australian universities, together with representatives from ANSTO, and the presentations were in the main made by the leaders of the groups to provide the maximum clarity as to what is being done. The conference was hosted by Professor Colette Boskovic and the University of Melbourne with sponsorship from Exciton Science, Bruker, Davies Collison Cave, Domo Technica and Malvern Panalytical. Industry representation was rather thin apart from patent attorneys and a water treatment/corrosion scientist. There were about 50 registrants. The format of 10-minute talks followed by five minutes of discussion maximised the number of presentations (21) plus a round table

discussion, and ensured that a high level of attention was maintained.

The program on current research was preceded by a short account on the history of rare earth activity in Australia (Glen Deacon). This concentrated on industrial activities but also included a brief account of the limited academic research initiated prior to 2000. The scientific program began with a lecture on the application of polymer inclusion materials for rare earth separation (Charles Croft). This work is very relevant to the need for greener separation methods. There were several lectures on synthetic methods, structures and reactivity (Peter Junk, Max Massi, David Turner). There were even more lectures on materials, molecular and supramolecular, usually linked to other properties such as luminescence and/or magnetism (Carol Hua, Max Massi again, John Stride,

Colette Boskovic, Scott Solvay, Alexander Brown) and on more theoretical approaches to single ion magnets (Marcus Giansiracusa). Technique-oriented lectures included advanced photophysical characterisation of luminescent lanthanoid complexes (Evan Moore), inelastic neutron scattering to determine crystal field excitations (Richard Mole), and mass spectrometry to study transmetallation and electron transfer in ytterbium tetraphenylborate systems (Weam Altalhi). Studies of biological systems by luminescence and magnetism (Leila Hill) and of radionuclide therapy and of neutron capture agents for cancer treatment (Ben Fraser) were another important direction. Solid-state rare earth chemistry was represented by pyrochlore oxides (Brendan Kennedy) and rare earth doped perovskites (Alexander Brown). On the applications side, we had rare earth corrosion inhibitors (Anthony Somers) and maximising value from rare earth discoveries with patents (Claire Gregg).

The final session included a talk from John Stride on experiences from talking to industry, which many of us have found less than rewarding, and then a discussion on the future of the meetings, one to be held next year in Western Australia to be arranged by Max Massi at Curtin University, possibly in collaboration with CSIRO. There was then a general discussion on ways forward, perhaps through concerted action, but the elephant not in the room was the ANSTO Minerals group with their history of extensive collaboration with industry in processing rare earths, and their capacity for solvent extraction research. It also should be noted that the chair of the conference gave an exemplary example of fitting a lecture to a tight timetable and that one pleasing feature of the conference was the widespread adoption of the IUPAC 'lanthanoid' instead of the hitherto ubiquitous 'lanthanide'. A lesson to the USA!

Glen Deacon FRACI CChem, **Colette Boskovic** FRACI CChem and **Peter Junk** FRACI CChem

A new face at RACI

Peter Gostelow is a new face at RACI, taking on the role of Manager, Membership and Programs. With extensive experience in membership organisations and educational program management, across a range of industries, Peter is well equipped to take on this new challenge.

Starting at the beginning of May, the team at RACI had the opportunity to meet Peter and learn more about his background and vision for working with them all to ensure members are fully engaged and making the most of what the organisation has to offer them. Peter told the team he has a genuine passion for building engaged member-supportive communities and is committed to supporting members in their professional development and whole-of-career journey. Peter emphasises the importance of collaboration and communication in driving the success of RACI.

Peter acknowledges the challenges facing the chemical industry in Australia, including the need to address sustainability and environmental concerns. He understands the importance of innovation and collaboration in the sector in the search for solutions to these challenges and believes that through a shared vision, RACI can become a hub for innovation and thought leadership in the industry.

Shenal Basnayake CEO of RACI was impressed by Peter's enthusiasm and background. He expressed RACI's excitement about the opportunities that Peter's leadership will bring to the organisation and the wider chemical industry in Australia. This coupled with Peter's commitment to building strong relationships with members and industry partners will no doubt mean you will see some exciting initiatives in the future.

The Board and Executive management congratulate Peter on his appointment and wish him all the best in his future endeavours with RACI.



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20 years of service to RACI for Mary Pappa

Congratulations to Mary Pappa for her incredible 20 years of service to RACI! Mary's journey with the Institute has been quite remarkable, starting from her interview on 8 May 2003, when she was offered the job on the spot and began working the same day. Initially, she worked doing administration for the Chemistry in Australia Committee for two days a week, allowing her to balance work with her children's primary school schedule. As time went on, Mary's responsibilities increased and she transitioned to assisting the

accountant, gradually working three and then four days a week.

In 2009, Mary faced a significant challenge when the Institute went through five accountants, leading the CEO to turn to her for help. Despite not having a background in accounting, Mary took on the role of Finance Officer. While it was difficult at first, she persevered and learnt everything she needed to fulfill her new responsibilities. Since then, Mary has been a crucial part of the Institute's financial operations, showcasing her dedication and adaptability.

Throughout her two decades with RACI, Mary has witnessed significant changes, including six CEOs and more than 14 President transitions, a large office renovation and numerous

National Congresses and events. Despite these changes, Mary has remained constant, providing her knowledge, competence and kindness to staff and members alike. Her warm and caring attitude has helped foster a sense of 'team' among her colleagues, making her a very cherished member of staff.

Mary's longevity at RACI is truly impressive, with only one other person having worked longer in over 100 years. When asked how she has managed to last so long, Mary humbly admits that she doesn't know. However, her genuine enjoyment of her job has played a significant role in her dedication and commitment.

Outside of work, Mary enjoys spending time with her family, dining out, chocolate, going on holidays, listening to her beloved Elvis and supporting the Essendon footy club. These hobbies provide a well-deserved break from her professional responsibilities and contribute to her overall happiness and well-being.

On this special occasion, we extend our heartfelt gratitude to Mary for her exceptional service and her invaluable contributions to RACI. Her knowledge, competence and caring nature have left a lasting impact on the Institute and the people she has worked with.

Thank you, Mary, for your outstanding dedication over the past 20 years.

On this special occasion, we extend our heartfelt gratitude to Mary for her exceptional service and her invaluable contributions to RACI. Her knowledge, competence and caring nature have left a lasting impact on the Institute and the people she has worked with.



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Lessons in chemistry

Garmus B., Penguin Random House, 2022, paperback, ISBN 9781804990926, 400 pp., \$22.99

The first novel by Bonnie Garmus rapidly drew accolades and rave reviews. The setting is 1950s–1960s US in the then male-dominated profession of chemistry. The main characters are a feminist fighting for equality, a male partner nominated no less than three times for the Nobel Prize, an almost human dog trained to have a horrendous unspoken vocabulary, and a child named ‘Mad’ born

out of wedlock. Other characters contribute to positive outcomes, including a mysterious philanthropist supporting education and research. Unfortunately, there exists an assortment of male bastards who think little of plagiarism, falsity and sexual harassment that contribute to everything negative; for example, ‘women make good secretaries and lab technicians’.

The heroine is the highly intelligent though often uncompromising Elizabeth Zott. She asserts she is a research scientist, following a master’s degree in organic chemistry at University of California, Los Angeles. She confronts a series of tragic events likely to knock the socks off most people, but soldiers on.

Elizabeth is raped by her supervisor as she joins the UCLA PhD program, and relocates to the Hastings Research Institute to follow her interests in abiogenesis, on low remuneration compared to equivalent male researchers. There she discovers the opulent laboratory of the prestigious Calvin Evans (a brilliant American-born Cambridge chemist and rower). Following an initial confrontation, the pair eventually fall in love, move in together, row together competitively, join forces in research, but agree not to marry.

The untimely death of her soulmate Calvin hastens her departure from Hastings once the Chief of Research (a Harvard rower) learns of her pregnancy – an unmarried mother! Her epitaph to Calvin bears the formula of oxytocin (albeit with typographical errors) – sometimes called the ‘love hormone’.

Mad, Elizabeth and Calvin’s child, is about four years old when Elizabeth, almost destitute, approaches the ‘Chief’ at Hastings for help. He engages her as a lab technician and asks to see what progress she may have made in her home laboratory. She provides her notebooks for his scrutiny. Later, the Chief plagiarises her work in a scientific publication. She resigns in desperation.

Fortuitously, Elizabeth discovers Mad is providing her special lunch to another girl at school. She arranges to educate the girl’s sole-parent father, a relatively ‘junior’ TV producer. Elizabeth is about to become the reluctant star of America’s most beloved cooking show *Supper at six*.

Elizabeth’s unusual approach to cooking includes teaching

chemistry, unafraid of terminology. On reading examples in her programs, I realised how little formal chemistry courses address food chemistry, and yet many chemists are good cooks.

As Elizabeth’s TV following grows, not everyone is happy; she is not just teaching women to cook, she is promoting that chemistry is about change, and in so doing dares her audience to change the status quo.

The characters become quite real and our heroine finally triumphant, while several ‘baddies’ receive their just deserts. Although the novel is a little long, it proves a provocative and enjoyable read about aspects of the chemist’s evolving world.

Dr Alan J. Jones FRACI CChem

The matter of everything: twelve experiments that changed our world

Sheehy S., Bloomsbury Publishing, 2022, hardback ISBN 9781526618962, paperback ISBN 9781526618955, ebook ISBN 9781526618986, 336 pp. approx., \$23–40

The matter of everything: twelve experiments that changed our world by Suzie Sheehy ticks all my boxes. The front cover cites a reviewer, ‘A splendid idea, vividly carried out: I enjoyed this book enormously’.

Excerpts from reviews printed on the back cover use terms such as: ‘fascinating and highly readable’, ‘action packed thriller’, ‘magical tour’, ‘sometimes how [scientific] discoveries came about is even more interesting than the discoveries themselves’, and ‘storytelling at its very best’. I could not agree more with these remarks. This is wonderful, educative, superbly written and absolutely an enjoyable book.

Frankly, some accounts of great moments in science are just plain boring. Why? Well, for a start, they are often pseudo-pontifically delivered from on high in convoluted language, styled in the third person past tense, and totally devoid of any mention of the ‘messy stuff’ in the background. But science is about people too and, with the exceptions of thee and me, people are weird! They bring to every situation their own sense of foibles and hunches, strengths and prejudices, biases, prior knowledge, drive, obdurateness and other facets of their idiosyncratic personalities. It is from this roiling ‘mess’ of humanity and its interactions that great science emerges. And that is exactly why this book so captivated me: Suzie Sheehy has excellently captured both the ‘science’ and the ‘people’ and the excitement of science in this very readable, user-friendly account.

Selecting just 12 experiments from the many that have substantially changed our views on how the physical world works is no mean feat. This book is organised in three sections: dismantling classical physics; matter beyond atoms; and the standard model and beyond. The narrative moves from the



discovery of the cathode ray tube, X-rays and the electron, through cloud chambers and particle accelerators to the discovery of quarks and the Higgs boson, a period ranging from the 1890s to the present. For we chemists, much of the material in the book underpins our knowledge of how the world works, although I confess the Higgs boson may pose a task for chemists of the future.

Author Sheehy is an Australian physicist, science communicator and academic with joint appointments and research groups at the University of Melbourne and the University of Oxford. *The matter of everything* is her first book. It demonstrates her great skills as a scientific communicator, and I keenly look forward to reading her future book communications.

Who should read this book? I am confident anybody with an interest in how science got to where it is will be enriched by reading this book. It is intelligible for most people from high teens onwards, with minimal scientific background. It is beautifully written and clearly explained. What is not to like? Buy it and read it. You are in for a treat.

R.J. Casey FRACI CChem HLM



How the world really works: a scientist's guide to our past, present, and future

Smil V., Penguin Random House, 2022, hardback ISBN 9780241454398, paperback ISBN 978024145404, 448 pp., \$24.99

Vaclav Smil's latest book is a masterful summation of where our planet is at, how it got there and what the future might hold in our quest for a low-carbon world. In plain, simple, well-argued, logical terms, Smil explains how internationalisation of trade

and manufacturing has had both desirable and undesirable consequences. Couple these considerations with a rising global population, which needs to be fed and housed, and the situation starts to look grim. And add in a widespread lack of substantive government and popular commitment to rapidly advancing the (drastic) changes necessary to create really effective climate amelioration, and we are facing a fairly gloomy future. The book is not advocating a 'do nothing' approach to climate change. Rather, it is more pointing out the formidable obstacles arrayed against climate mitigation and suggesting we should not be very amazed when we fail.

The book takes its reader through a series of reality checks that influence our survival and prosperity. Smil uses energy as the only true universal measure of value. So, for example, a carrot embodies all the energy it took to plough the field, fertilise, control the weeds, harvest and get said carrot to the

supermarket. This can also be expressed as a volume equivalent of diesel. A greenhouse-grown tomato can be represented as about 100 millilitres of diesel or 500 mL/kg. If you fancy a roast chicken, you are looking at about 350 millilitres of diesel per kilogram of chicken. This concept of embodied energy is particularly useful in considering food production and in mapping productivity. Without enormous consumption of fertilisers (principally ammonia), global famine would be endemic. And how do we make ammonia? We use the Haber-Bosch process (temperature ~500°C, pressure ~300 atm). Plenty of CO₂ there! It is interesting to explore this notion that when we consume food, we are consuming fossil fuels. Similarly, as well as fertilisers, the other materials Smil considers as 'essential' – steel, cement and plastics – consume large amounts of energy to make as well as having their own environmental issues. He currently does not foresee any rapid decline in our reliance on fossil fuels, a dependence that will not be severed without considerable effort and expense. To be fair, he also discusses the nature of risk and the dangers inherent in extrapolation. He could be wrong, but I do not think so! Alas, we are where we are and, as Smil cogently points out, there is no going back.

We are not dealing with some crackpot doomsday merchant or nay-sayer here. Vaclav Smil (b. 1943) is the world's leading expert on energy and an amazing polymath. He has been at the University of Manitoba since 1972 and is a distinguished professor in the environment faculty. He is justly famous for his works in clarifying the facts relating to energy and climate change. His views are generally neither pessimistic nor optimistic but clear, cogently argued and extensively referenced statements about the scenario we live within. Frankly, there is no escaping Smil's relentless logic. In many ways, this book is a crowning assembly of his views on some of the major issues engaging humanity by one of the greatest minds of our times.

Views on climate change and what we humans ought to do about it cover a wide range from the ratbaggy of climate change deniers, through a middling position that agrees change is occurring but doing anything much is nigh on impossible (and besides, the world has been hotter, and colder, before and endured very much higher CO₂ levels; species come and species go ...) to a more zealous position where a problem is seen and ameliorating strategies sought to solve it. Scientists by and large fit into the last category. The real strength of this book is that it will greatly assist you, my fellow scientist, in getting a firmer hand on the climate problem and possibly give you new insights into avenues of thinking about the problem.

Everybody should read this book. Surely, the more we understand the mess we are in, the better our chances of doing something about it. There is an old Latin motto that translates as 'Knowledge is power'. Read this book and get the power!

R.J. Casey FRACI CChem HLM

Nobel laureate Brian Schmidt's big ideas for how Australia funds and uses research

This article is part of a series on big ideas for the Universities Accord. The federal government is calling for ideas to 'reshape and reimagine higher education, and set it up for the next decade and beyond'. A review team is due to finish a draft report in June and a final report in December 2023.

Education makes Australian citizens healthier, wealthier and more engaged with society. At the same time, government-funded research in higher education drives economic productivity in ways other government funding does not. Together, the future of Australian prosperity depends on the education and research undertaken within its tertiary education system, and especially our universities.

The Australian higher education system has served Australia well over the past 30 years, but it is not fit for the rapid pace of change to which the world will be subjected over the coming decades. If Australia is going to remain the 'lucky country', we are going to have to make more of our own luck.

The federal government's call for 'lasting reform' for Australian universities with the Universities Accord offers a timely opportunity to take action.

In my personal submission to the accord process, I outline three big ideas to help reset higher education to deliver the system Australians need and deserve. The first is to provide each Australian with lifetime access to a single higher education system, spanning both university and vocational education.

In this piece I want to focus on my other two big ideas – improving the way we fund and then translate research. These offer some of the biggest and easiest bang-for-buck solutions we can enact.

Australia's research ecosystem

Australia's research ecosystem has become highly reliant on funding via cross-subsidies from international student fees. Currently, Australian government expenditure in research and development – expressed as a fraction of GDP by the OECD as 'GBARD' – is the lowest of the world's advanced economies and is continuing to decline.

Currently, Australian government expenditure in research and development ... is the lowest of the world's advanced economies and is continuing to decline.

Instead, universities now spend more on research (using international student fees) than the government. This does not happen in other advanced economies.

Compounding this is the fact government funding of directed research for national benefit is short term, ad hoc, not strategically planned across agencies, and is poorly aligned to university planning timescales. Over the past seven years as Vice-Chancellor of the Australian National University, I have seen dozens of different programs across various government agencies come and go with no overall coordination.

Research funding is also not fully integrated with workforce and major equipment needs, and this all leads to shortfalls in key areas of national research need. For example, if we look at critical minerals, the research infrastructure that underpins earth science is completely absent in planning and funding.

Universities, government and business are not working together on the big research issues facing Australia. To fix this, Australia urgently needs a fully funded core sovereign research capability. We also need to better translate research beyond universities to the real world.

We need to identify and properly fund sovereign research

Sovereign research capability is about Australia being able to fund and undertake the research it deems vital to its national interests.

We must identify the core set of sovereign research capabilities necessary for the future security and prosperity of the Australian people. And we must fund these activities in full (including overheads), without the need of cross-subsidies from non-domestic sources. This requires a whole-of-government approach.

This core research should be expected to be uniformly excellent. It should include curiosity-driven research as well as research looking at practical solutions to existing problems ('applied research'). It should also go beyond technological developments to support the vibrancy of Australian democracy and culture.

A large fraction of the sovereign curiosity research money should be competitively allocated via existing bodies, the Australian Research Council and National Health and Medical Research Council grant system.

We need to make it easier to translate research

In addition to fully funding sovereign research capabilities, we must also rethink how we fund research translation for the public good. This is the process whereby we move research from labs or journals out into the real world.

When we fund applied research, we need to be strongly focused on outcomes. This includes the government directing

funding for specific missions in areas of national need. This could be long term, with timeframes of five to 20 years.

Independent expert-based boards would be given a budget to achieve specific goals within a time horizon, and invest across industry, government and the research sector to achieve these goals. This would replace current schemes for translating top-down government priorities.

In addition, we need a new suite of agile 'bottom-up' supports for individuals' ideas. This would also replace existing research translation schemes, which have typically been 'set-and-forget' investments, without an expert stewardship over the ten-year-plus cycle necessary to get globally competitive capability.

Projects should be closely monitored and defunded when progress is deemed insufficient. Expert panels could also work with the private sector to rapidly increase investment of such programs when commercially justified.

Funding programs need to pay particular attention to the areas of market failure. Such a system should not crowd out existing private technology transfer, but do things that will not otherwise happen, and better connect industry, government and academia in the research ecosystem.

Blue-sky thinking

The foundational research done in universities underpins the sovereign capability of the nation to increase productivity, improve health and wellbeing, remain secure, and to solve and adapt to challenges that face society. This is the research universities do that leads to new products, jobs and industries never envisaged when the research cycle begins.

Work just in my own area of astro-particle physics has underpinned the WiFi, camera, GPS and touch screen of your phone, not to mention many recent start-ups across Australia.

But most of the value created for Australia is actually through indirect productivity spill-overs. These are the people, ideas and capabilities created by Australian research that find their way in thousands of ways into Australia society that allow us to do more for less.

These are hard to measure, and emerge with a considerable lag, but our best estimates are that they are large. Government has a special role in funding this activity, as firms cannot typically capture the benefits of this work.

International education is becoming increasingly globally competitive. The margin from international student fees Australian universities are so reliant on to fund their research is bound to drop over coming decades.

So as part of a sovereign research capacity, Australia should set a minimum level for government-sponsored foundational research as a fraction of GDP. This would bring Australia in line with other nations with advanced economies.

And if all universities are expected to undertake excellent research, a base amount of research funding should be made



Research funding in Australia has become very reliant on university fees from international students. Martin Adams/Unsplash

available through either student-based allocations or another mechanism. Alternatively, new types of future higher education institutions could have research dropped from their mission entirely.

Making our own luck

Australian universities and their research have for many years made Australians' lives and our world better. The government's accord process gives us the chance to make sure our universities can continue to deliver on this promise for our future generations.

But we must act, and this action must take serious stock in how we fund and translate research in Australia today.

If we fail to value and fund university research in the way that we need, and should, the so-called Lucky Country might just run out of luck.

Professor Brian Schmidt is the 2011 Nobel laureate in physics and Vice-Chancellor of the Australian National University. This article is based on his individual submission to Universities Accord review. First published at theconversation.com.

Making an Australian genetic medicine manufacturing ecosystem

Consider the huge advances being made in nanomedicine, and the growth of a few giants whose products are perfectly matched to the emerging needs of the COVID-19 pandemic. Their juggernaut continues, with little indication it will slow. A key driver is the opportunities to use the multitude of RNAs (e.g. mRNA, siRNA) in the treatment of many currently untreatable diseases. These uses are becoming a reality largely due to the capacity to encapsulate RNA for delivery in a form that can circumvent the body's defences.

The promise of local manufacture, led more by scientific endeavour and less by the profit matrix of pharmaceutical giants, calls for an elegant disruptor in nanoparticle production, something that not only encapsulates RNA and other molecules in the laboratory but does so seamlessly and efficiently at scale. Micropore Technologies, a UK-based company with its roots in micromixing and emulsions, is expanding developments in the fundamental understanding of crossflow mixing technology research at Loughborough University. Engineers, scientists and pharma process control experts are designing a new way to solve the scaling production puzzle by developing advanced crossflow (AXF) mixing technology. It ticks all the fundamental boxes for the production of nanoparticles, such as mixing rates

being faster than assembly rates and mixing being in laminar flow – and importantly it is not limited by volume.

This technology brings the possibility of producing vaccines for a multitude of diseases at a rate of 1500 litres an hour – about 58 000 doses every minute – from something that could fit into a small briefcase (youtu.be/1aaNwVTFcFg). To give context – the annual global production of Pfizer's COVID vaccine in 2021 was three billion doses. Just one AXF mixer (the AXF-7) could arguably create the same number of doses in six months.

Precision-engineered, crossflow micromixing equipment allows for thorough, reproducible nanoformulation at scales ranging from microlitres up to hundreds of litres, using gentle laminar flows. The intuitive design and stainless-steel construction make good manufacturing practice (GMP) production of narrowly dispersed, accurately sized nanomedicines easier than ever before. Given the small footprint required and the simplicity of design, it is likely this will be the future of production; there is no need to build a factory. This technology makes a deal of sense: in a GMP setting, it is clean in place or steam in place, making it possible to achieve without the need to continuously buy consumables at exorbitant prices of hundreds of thousands of dollars just to run a single batch of just 50 or 100 litres.

In her review of current and emerging mRNA technologies (bit.ly/3JS0IcY), Jennifer Huen of Beagle Scientific concluded 'Although IJM [impinging jet mixers – used by Pfizer in COVID vaccine production] is currently the encapsulation method of choice for mRNA vaccine manufacturers, the economic and environmental potential for advanced crossflow in gene therapies, RNA/DNA vaccines, protein-based drugs, and other biologics cannot be overlooked'. She also noted, 'The scalability of crossflow mixing made it possible to develop a single instrument that covers the volumes needed from discovery to the clinical phase'.

Thanks to nanoformulation and microfluidics, Australia is on the cusp of local manufacturing of genetic medicines on a scale never seen before, with opportunities for global, equitable access, research and infrastructure to fit the evolving RNA science ecosystem.

The importance of RNA science to Australia (bit.ly/40DTS3k) has been highlighted by the beginnings of the UNSW RNA Institute. On 20 February, the New South Wales government of the day announced that Australia's first RNA research and pilot manufacturing facility will be built at Macquarie University and operated by Myeloid Therapeutics, headed by CEO Dr Daniel Getts.

From the very early days of planning, the now New South Wales shadow Minister for Health The Hon Brad Hazzard worked tirelessly to bring this facility to fruition, probably before my letter in 2020 discussing the need to create a genetic medicine



Dai Hayward, CEO Micropore Technologies (left), and RACI President Professor Palli Thordarson at the UNSW RNA Institute

manufacturing ecosystem was forwarded to him by The Hon Gabrielle Upton. In a media release, Hazzard stated, 'Investing in RNA research and manufacturing will ensure New South Wales remains a world leader in the development of medical technologies and therapeutics, which will ultimately deliver better patient outcomes, particularly for cancer and rare genetic diseases'. Let's hope the new government will advance this initiative. Down the Hume in Canberra, the Shine–Dalgarno Centre for RNA Innovation integrates world-leading RNA biology research with advanced enabling infrastructure, allowing us to meet future biomedical challenges in partnership with industry, government and academia (bit.ly/3LUvThn). They are continuing work first described 50 years ago in the *Nature* article 'Conserved terminal sequence in 18S rRNA may represent terminator anticodons' (bit.ly/3IK6p6t). This ribosomal binding site in bacterial mRNA became known as the Shine–Dalgarno sequence, and the impact of such RNA science research and innovation is the subject of the Shine–Dalgarno Symposium, to be held 5–7 June.

The RNA science ecosystem continues to grow, with the Queensland government announcing a partnership with healthcare giant Sanofi to create a global mRNA vaccine hub (bit.ly/42Ix2Lv). This capacity building complements the brilliant work of the Translational Research Institute, Griffith University and the University of Queensland (including the BASE facility, which builds mRNA vaccines and therapies).

Continued funding from the Victorian government, the location of Moderna, Pfizer and the new CSL facilities – coupled with the existing excellence at Monash University, the Monash Institute of Pharmaceutical Sciences, the University of Melbourne, the Doherty Institute, CSIRO, St Vincent's Institute, the Hudson Institute of Medical Research and RNA Victoria – means that RNA science in Victoria is incredibly strong too. Let us not forget the Australian and New Zealand RNA Production Consortium – the original driving force of these incredible developments (bit.ly/3LVsE3W). I met the original team during lockdowns over many Zoom meetings, developing strategies and creating connections with government, public servants with the aim to develop a genetic medicine manufacturing ecosystem in



Micropore AXF mini mixer scales from benchtop to commercial-scale continuous manufacturing.

Australia. They were recognised in the *Sydney Morning Herald's* 'Australians who mattered' in 2021 (bit.ly/3nvm1uW).

New South Wales has brought together about a dozen institutions to work in collaboration; this is not a simple task. How do we shape this into a national approach? I can only echo the sentiments of an Australia leader in RNA science, Associate Professor Traude Beilharz of Monash University: 'Without significant incentives from government, most of us would be driven by the career-metrics of our institutions/funders, which, despite all the talk of collaboration, still favour the "hero" who does everything by themselves'. A federal government approach to fund and assist in national strategy would encourage collaborative research, ensuring we play to our strengths without replicating effort while identifying the gaps in state investment, building a truly national world-class ecosystem that can mobilise at times of patent need.

What all this suggests is that Australia is well on the way to a thriving industry in RNA science, and that with a little more effort it can set a global benchmark.

Peter Davis is an applications scientist at ATA Scientific (www.atascientific.com.au). Dai Hayward, CEO Micropore Technologies, will speak on the issue of robust scalability of nanomedicines from discovery to manufacture at Sydney's NanoMedicine 2023 Conference on 19–21 June. He is joining an RACI Pharma Group webinar to discuss the same topic with RACI President Professor Pall Thordarson on 14 June (see page 42).

Splitting water in a green hydrogen climate

Almost all of the so-called 'grey' industrial hydrogen produced at present comes from fossil fuel feedstocks that contribute directly to the climate warming problem. The future production of green hydrogen must therefore be based on the other possible route, the splitting of water – by either electrolysis or photolysis.

Direct solar splitting of water, or photolysis, uses light energy to split water into hydrogen and oxygen. These photolysis processes are currently at initial stages of development but are expected to provide a long-term source of green hydrogen. The electrochemical method, using electrolyzers, is therefore expected to be the preferred route to green hydrogen for the near future. These electrochemical technology systems range in size from small to exceptionally large. Small systems are comparable in dimensions to a ship's container for adjacent use (e.g. to deliver fuel or to store energy), while large systems, such as those supplied by Siemens Energy, can generate up to 50 000 tonnes of e-methanol formed from renewable hydrogen and biogenic carbon dioxide. This large process can avoid 100 000 tonnes of carbon dioxide emissions annually in shipping, by replacing fossil fuels.

The role of green hydrogen in climate remediation has been covered extensively in the international media. Carbon emission targets across many developed countries will require massive scale up and acceleration of renewable hydrogen production. It is recognised that hydrogen fuel cells in transportation have several advantages over battery-powered electric motors in addition to having zero greenhouse emissions. These advantages include greater power and longer range with no dependence on the critical metal elements for batteries, namely lithium, cobalt etc. The fact that hydrogen is the most common element in the universe is clearly an advantage.

The rapid recent development of commercial large-scale water electrolyzers for hydrogen production is a strategic step as the world approaches the economic tipping point of \$2/kg of hydrogen. Once this tipping point has been crossed, green hydrogen will become increasingly competitive against fossil fuels. It is important then that Australia is engaged in developing large-scale hydrogen production projects.

The rapid recent development of commercial large-scale water electrolyzers for hydrogen production is a strategic step as the world approaches the economic tipping point of \$2/kg of hydrogen.

Initial offtakers of the CS Energy Kogan hydrogen project near Chinchilla in Queensland's Western Downs region include Sojitz Corporation, supplying green hydrogen to Nauru to assess replacement of fossil fuels in marine vessels with hydrogen. Other clients are interested in the development of modular hydrogen refuelling stations in the heavy transport and haulage market in southern and western Queensland.

Once commissioned, the ENGIE Yuri electrolysis plant, in a joint venture with Japan's Mitsui and Co Ltd, will generate renewable hydrogen for use in Yara Australia's ammonia facility at Karratha in the Pilbara region of Western Australia. Among the largest of its kind in the world, the plant will include a 10-megawatt electrolyser powered by 18 megawatts of solar photovoltaics and supported by eight megawatts of battery storage.

The competitive Townsville Region Hydrogen Hub program will deliver federal government funding towards projects that accelerate the development of a hydrogen industry in North Queensland. This is part of a larger government investment in the North Queensland region in renewable hydrogen as fuel, energy generation and storage, and as chemical feedstock. It will extend the Regional Hydrogen Hubs Program for projects in locations such as Gladstone, the Hunter Valley, the Pilbara, Port Bonython and Bell Bay.

The looming \$2/kg economic tipping point will be the effective launch point of the long-awaited green hydrogen economy. The global market size is projected by MarketsandMarkets to increase from US\$676 million (A\$1000 million) in 2022 to US\$7314 million (A\$11 000 million) in 2027. The hydrogen market compound annual growth rate is projected to be 63.4% by 2027. Massive investments in the USA are a central driver of this growth. MarketsandMarkets list the several major international companies already involved in green hydrogen technology.

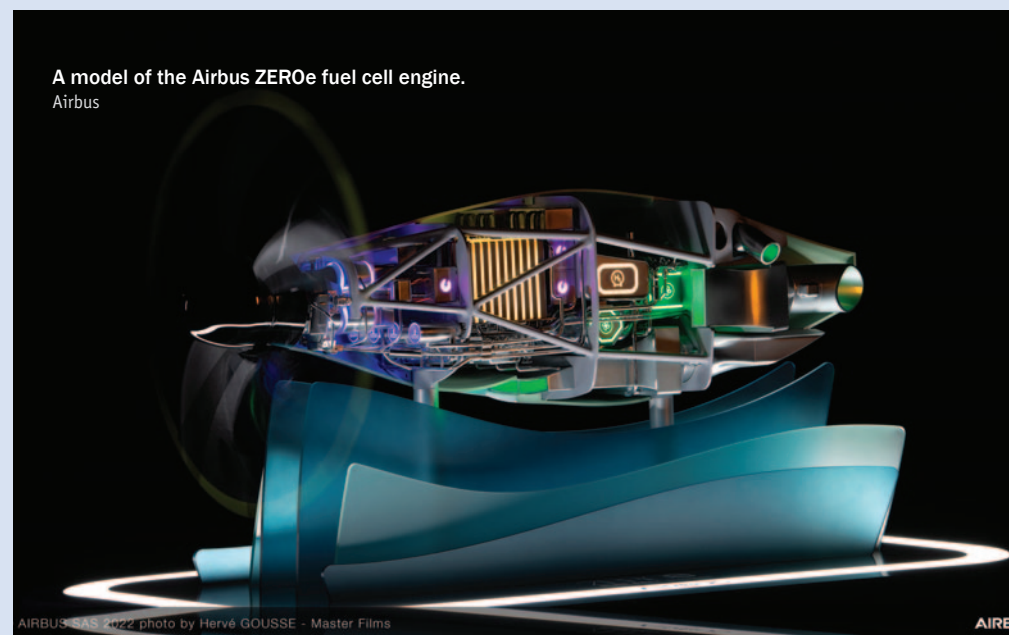
Given the expected massive growth in demand over the coming decades for green hydrogen from electrolyzers, a global problem has been identified. The world has a critical shortage of fresh water, which is required for most electrolyser systems. This has led researchers from universities in China and Australia (reported in *Nature* November 2022) to develop an electrolysis system based on seawater, and the hydrogen produced is called 'Blue H2'. A demonstration of this system operating over 130 days produced 386 litres of hydrogen. The authors claim that this Blue H2 method is cost efficient and scalable in a comparable way to the existing electrolysis systems using fresh water. A problem with this approach is the production of the toxic and corrosive chlorine gas from chloride at the anode of the electrolysis system. Natural cations in seawater, such as magnesium and calcium, form by-products that reduce the efficiency of the system. The research team has redesigned the membrane system to create a design that maintains a constant flow of clean water to the electrodes while excluding the cations and seawater impurities. The researchers are now

Airbus models hydrogen-powered, zero-emissions engine

Late last year, Airbus announced that it is developing a hydrogen-powered fuel cell engine. The propulsion system is being considered as one of the potential solutions to equip its zero-emission aircraft that will enter service by 2035.

Airbus will start ground and flight testing this fuel cell engine architecture on board its ZEROe demonstrator aircraft towards the middle of the decade. The A380 MSN1 flight test aircraft for new hydrogen technologies is currently being modified to carry liquid hydrogen tanks and their associated distribution systems.

‘Fuel cells are a potential solution to help us achieve our zero-emission ambition and we are focused on developing and testing this technology to understand if it is feasible and viable for a 2035 entry-into-service of a zero-emission aircraft’, said Glenn Llewellyn, VP Zero-Emission Aircraft, Airbus. ‘At scale, and if the technology targets were achieved, fuel cell engines may be able to power a 100-passenger aircraft with a range of approximately 1000 nautical miles. By continuing to invest in this technology, we are giving ourselves additional options that will inform our decisions on the architecture of our future ZEROe aircraft, the development of



which we intend to launch in the 2027–2028 timeframe.’

Airbus identified hydrogen as one of the most promising alternatives to power a zero-emission aircraft, because it emits no carbon dioxide when generated from renewable energy, with water being its most significant by-product.

There are two ways hydrogen can be used as a power source for aircraft propulsion. The first way is by hydrogen combustion in a gas turbine, and the second is by using fuel cells to convert hydrogen into electricity in order to power a propeller engine. A hydrogen gas turbine can also be coupled with fuel

cells instead of batteries in a hybrid-electric architecture.

Hydrogen fuel cells, especially when stacked together, increase their power output, allowing scalability. In addition, an engine powered by hydrogen fuel cells produces no NO_x emissions or contrails, thereby offering additional decarbonisation benefits.

In 2020, Airbus created Aerostack, a joint venture with ElringKlinger, a fuel cell systems and component supplier, and later that year presented its pod concept, which included six removable fuel cell propeller propulsion systems.

Airbus

improving the efficiency of this pre-cleaning system. They also claim that their seawater system can recover useful by-products, including the critical alkali metal lithium, and may be adaptable to other applications such as cleaning up industrial wastewater.

A more significant issue with hydrogen has been identified in a recent report from the UK Government (bit.ly/40iQZEx). Hydrogen is an indirect greenhouse gas and its reactions with hydroxyl radicals in the atmosphere may offset the advantages of hydrogen as a non-carbon-emitting gas. This impact is being investigated at present, but if proven this observation makes it imperative that hydrogen leakage into the atmosphere from pipelines and other distribution infrastructures are kept to an absolute minimum. This means that the cost and efficiency drive to convert natural gas pipelines into hydrogen pipelines will have to be carefully refined. This problem is exacerbated by the greater ability of the lighter smaller hydrogen molecule to

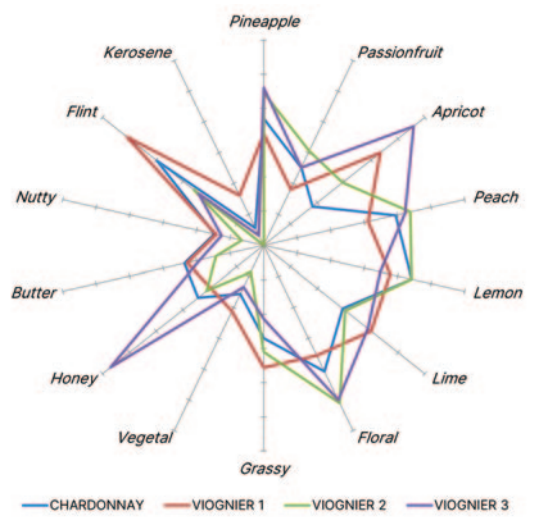
diffuse through junctions, gaskets and linings of the existing natural gas pipelines. It will also tend to favour the deployment of smaller-scale distribution technologies for hydrogen that are adjacent to applications such as refuelling of vehicles, and which minimise the use of pipelines that may leak hydrogen.

An alternative existing strategy is to convert green hydrogen to green ammonia, which circumvents the hydrogen leakage problems and makes transportation of the green fuel more practical. A potential future method to make green ammonia would be by reacting green hydrogen from water electrolysis with nitrogen from the air in a Haber–Bosch process powered by sustainable electricity.



Ralph Cooney ONZM, FRSNZ, FRACI CChem has had a science and innovation career bridging New Zealand and Australia. He was former University of Auckland Pro Vice Chancellor of the Tamaki Innovation Campus, Dean of Science, Head of Chemistry and Science Leader of several major national research programs.

Chemical basis of ‘stone fruit’ aromas in white wine



Sensory profiles of four of the white wines studied.

Hundreds of volatile aroma compounds can be present in any one glass of wine, with these compounds coming directly from the grapes, made by the yeast, released from precursors during fermentation, derived from oak contact, or developing during barrel and/or bottle ageing.

‘Stone fruit’ characters are important flavour notes for several white wine varieties, such as ‘fresh peach’ in Chardonnay, ‘apricot’ in Viognier, and ‘dried apricot’ in sweet botrytised Semillon. But which volatile compound(s) cause these stone fruit aromas?

In fresh apricots and peaches, several *n*-alkyl γ - and δ -lactones are impact aroma compounds; that is, they smell like stone fruit. Some wine aroma studies using GC-olfactometry (GC-sniff) have suggested that they were the cause of peach or apricot aromas in wine. However, one study found only low concentrations of γ -octalactone and γ -nonalactone (<5 $\mu\text{g/L}$) in just a few dry white wines, well below their aroma detection thresholds (R.C. Cooke et al. *J. Agric. Food Chem.* 2009, vol. 57(2), pp. 348–52), suggesting they are not likely to be major contributors to stone fruit aroma in dry white wines. However, tenfold higher concentrations were found in the botrytised wines. Even at these moderate concentrations, synergistic effects between the lactones might explain their involvement in the ‘dried fruit’ aroma of botrytised wines (I. Jarauta et al. *Dev. Food Sci.* 2006, vol. 43, pp. 205–8).

To specifically target stone fruit aromas in dry white wines, Chardonnay and Viognier wines with differing stone fruit aroma intensities were subjected to extensive chemical analyses and sensory quantitative descriptive analysis (T.E. Siebert et al. *J. Agric. Food Chem.* 2018, vol. 66(11), pp. 2838–50). Notably, the wines studied differed strongly in their rated intensity of peach (defined as fresh white peach) and apricot (tinned apricots) aroma attributes (see diagram). A group of compounds were predicted from statistical models to be important for a wine to

have high apricot aroma. These included γ -nonalactone, γ -decalactone and (*Z*)-6-dodecenolactone, all at very low concentrations; the monoterpenes linalool, geraniol and nerol, at concentrations higher than you might find in a ‘floral’ variety such as Riesling; and the C_6 compounds (*E*)-2-hexenal and (*E*)-2-hexenol; plus aldehydes nonenal and benzaldehyde. The peach aroma attribute was associated with some ethyl and acetate esters, benzaldehyde and monoterpenes.

Reconstitution sensory experiments confirmed that the monoterpenes were the key aroma compounds responsible for the apricot attribute in white wine. This result was somewhat surprising because these monoterpenes are usually described as ‘floral’ and ‘citrus-like’. A follow-up reconstitution sensory study, looking more closely at the interaction of the monoterpenes with the aldehydes and the γ -lactones, verified monoterpenes as the major contributors for apricot aroma in wine, with an enhancing role from γ -lactones, and a masking effect by aldehydes (D. Espinase Nandorfy et al. *Aust. J. Grape Wine Res.* 2022, vol. 28(3), pp. 424–38).

As monoterpenes are grape-derived compounds, we ran vineyard studies to assess practical options for wine producers to be able to enhance the levels of these compounds. Large differences were found in monoterpene concentrations between Viognier clones through ripening, with regional and sun exposure differences also observed (T.E. Siebert et al. *Food Chem.* 2018, vol. 256, pp. 286–95; T.E. Siebert et al. 18th Australian Wine Industry Technical Conference 2022, Poster). Grape compositional differences were related to wine composition and sensory properties in a follow-up winemaking study. Region of origin was the most important factor, but clone and harvest date were also significant, for levels of apricot aroma and flavour in Viognier.

To confirm the compounds that result in peach aroma, the first reconstitution attempt in a Viognier model did not satisfactorily represent this aroma. But by using a Chardonnay model, fermentation-derived esters ethyl octanoate and ethyl hexanoate directed the more subtle peach aroma (Espinase Nandorfy et al. 2022). Also, consumer acceptance testing found that peach aroma in Chardonnay was positively linked to ‘liking’ scores (D. Espinase Nandorfy et al. *Aust. J. Grape Wine Res.* 2023, submitted). A Chardonnay winemaking study is underway at the Australian Wine Research Institute to assess differences in these peachy esters arising from fermentation variables, comparing yeast selection, degree of juice clarification and region.

Interestingly, these studies have found that the different stone fruit aromas peach, apricot and dried apricot are caused by three separate families of aroma compounds, and each family is formed from distinct parts of the grape-growing and winemaking process!

Tracey Siebert is a research scientist at the Australian Wine Research Institute, South Australia.

Thinking about Karl Ziegler

Every time I put the recycling bin out, I think of Karl Ziegler (1898–1973) because he gave us high-density polyethylene (HDPE), one of just three polymer types that I'm allowed to put in the bin because they are the only ones the recycling company that serves our area can handle. The other two are polypropylene (PP), another tribute to Ziegler, and polyethylene terephthalate (PET). Ziegler jointly with Giulio Natta was awarded the Nobel Prize in Chemistry in 1963. In April, the Karl Ziegler Foundation, founded by his daughter and awarding prizes to young scientists, held a jubilee conference to celebrate and reflect on his life and work and to ponder the future.

Property	LDPE	HDPE
Density (kg/m ³)	917–930	930–970
Melting point (°C)	115	131
Tensile strength (MPa)	21	38
Stretching (%)	400–700	15–100

Relating chemical structure to the density of solids is a game fraught with error, but in a limited family like this (and remembering that these are not rods but zig-zag chains) it's reasonable to expect the chains of HDPE to pack together better than their furry LDPE cousins, leading to higher density, melting point and strength. HDPE is used in many food containers, whereas LDPE is used in polymer films that also have food applications and in the screw caps of some containers. For example, both my milk and orange juice come in HDPE bottles, but the milk has an HDPE cap (over a foil seal) while the juice cap is LDPE. Go figure.

One of the clever things about the organometallic route to polyethylene is that it can be used to produce LDPE with varying degrees of 'L', by simply using a monomer mixture of ethylene with a higher alkene such as but-1-ene or hex-1-ene, so the resulting hydrocarbon chain has a proportion of two- or four-carbon side chains, respectively.

To return to my recycling theme, PET with its ester linkages in the chain is the easiest of the four to degrade by chemical or enzymic means, the latter being pursued by chemical engineers at ANU. Given the cost of collection and separation and the scale of operations, even successful technologies are unlikely to be economically competitive until the price of virgin material rises due to decline in the production of crude oil, or governments introduce legislation that forces manufacturers to use at least some of the recycled material no matter how much it costs. Don't hold your breath.

There seems to be no chemical or enzymic way to reconvert the other three polymers to monomeric alkenes that can be separated from rubbish and repolymerised. The best technology on offer appears to be the pyrolysis process developed by Thomas Maschmeyer (University of Sydney). There are opponents to this and also the burning of waste plastic for energy recovery, partly on philosophical grounds (actual recycling is preferred) and partly because of the consequent production of the greenhouse bogey, CO₂, but some such combustion must occur in the waste incinerators that are popular in Europe.



Ian D. Rae FRACI CChem (idrae@unimelb.edu.au) is a veteran columnist, having begun his Letters in 1984. When he is not compiling columns, he writes on the history of chemistry and is an editor of *Historical Records of Australian Science*.

Andrii Shyp/iStockphoto



On the bottom of containers are stamped the triangle identifiers. Have trouble seeing them? Try rubbing a marking pen over the stamp to enhance it. The diagram also shows the code for low-density polyethylene (LDPE), because that's where this story begins.

The first industrial polyethylene was made in 1933 by polymerising ethylene gas at high temperatures and pressures in the presence of a free radical initiator (R[•]). The first step produces a new carbon-centred radical, R-CH₂-CH₂[•], one more gives R-CH₂-CH₂-CH₂-CH₂[•], and eventually we need to represent the growing macromolecular chain as R-CH₂-CH₂-(CH₂-CH₂)_n-CH₂-CH₂[•] where *n* can be a very large number indeed. Like most simple pictures in chemistry, this one is a useful starting point but it doesn't tell the whole story.

Free radicals don't always do what we expect (hope?) them to do, and in this case, as the chain grows, every now and then the terminal radical doesn't grab a passing ethylene molecule, but instead 'bites back' on its chain and abstracts a hydrogen atom, leaving the radical centre a few carbons back on the chain. The structure looks

like this: -CH₂-C[•]H-CH₂-CH₂-CH₂-CH₃. The chain has not finished growing, of course, but growth takes off from that carbon radical, leaving a four-carbon branch dangling off the long chain. Other modes of back-biting can occur, too, so about 2% of the carbons in the long polymer backbone carry a side chain.

In 1953, Ziegler found a new way to polymerise ethylene, using triethyl aluminium and titanium tetrachloride to produce polyethylene at low temperatures and normal pressures. The mechanism is complicated but involves the first ethylene molecule bonding to the titanium to form CH₃-CH₂-TiCl₃, after which the next ethylene inserts into the carbon-titanium bond to form CH₃-CH₂-CH₂-CH₂-TiCl₃, following which a long polyethylene chain is quickly formed.

The difference in the physical properties of low-density and high-density polyethylene is small but very important (see table).

VCE Chemistry Teachers' Professional Learning Day
7 June 2023, RMIT University city campus, Melbourne
raci.org.au/events

Women in STEM as Trailblazers and Change-Makers
16 June 2023, Monash University Clayton and online
raci.org.au/events

1st Biennial Conference on Green and Sustainable Chemistry and Engineering
2–5 July 2023, Shangri-La Hotel, Cairns
gasc.au

20th International Conference on Biological Inorganic Chemistry
16–21 July 2023, Adelaide
icbic2023.org

RACI Qld Early Career Chemists Group careers panel
1 August 2023, 4–5.30 pm, The Atrium, Brisbane
raci.org.au/events

Mental Health in the Sciences
3 August 2023, 6–7 pm, online
raci.org.au/events

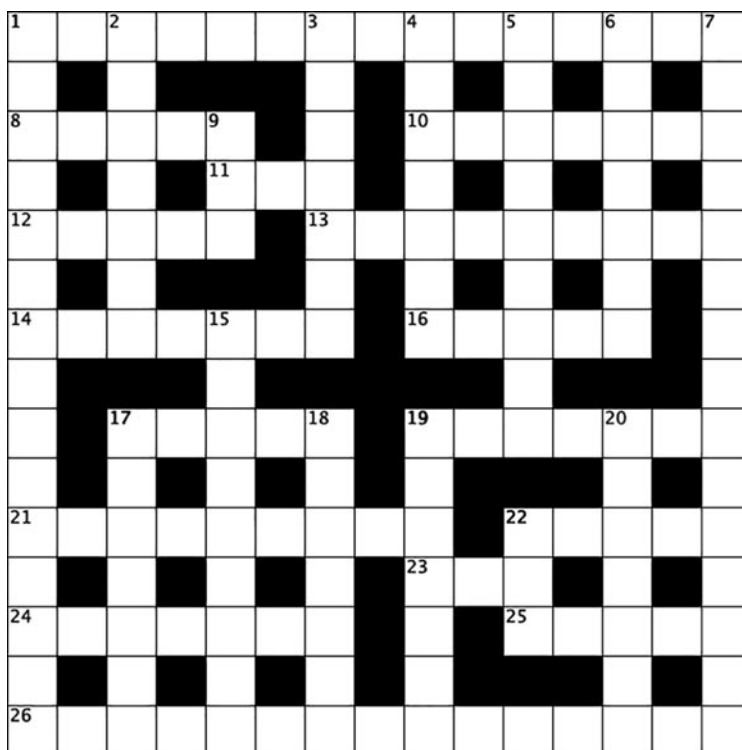
Working Conditions in Science
8 August 2023, 6–7 pm, online
raci.org.au/events

IUPAC World Chemistry Congress 2023
18–25 August 2023, World Forum, The Hague
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Across

- 1 Illuminates a C/I/O compound, a major component of clay. (15)
- 8 Tests flame with a mass spectrometer. (5)
- 10 Convert O_2 to O_3 over urezin ozocerite inclusion?! (7)
- 11 See 23 Across.
- 12 Greedily eat but hold over a molecule having adjacent atoms with opposite formal charge. (5)
- 13 Notemaker uses starch and oil. (9)
- 14 Strangely impedes a poetic half measure. (7)
- 16 Thermosetting resin using erythropoietin coordinates. (5)
- 17 Four elements relating to 26 Acrosses. (5)
- 19 The gang declares Spooner digests sugar. (7)
- 21 Lug in family with 58 authorisation. (9)
- 22 Spooner will spend a lot of time in prison subdivisions. (5)
- 23 & 11 Across Four elements with a dome-shaped structure. (6)
- 24 Garret in the French grid. (7)
- 25 Combines a series of bets in return! If you don't like it, lump it! (5)
- 26 On account the standard makes one laugh, I hear, it might be an ion. (7,8)

Down

- 1 2-Acetoxybenzoic formed from clay/salt/ I_2 cycle. (15)
- 2 & 4 Down Ration opium use to 235, perhaps. (7,7)
- 3 Dihydroxydisulfane is one! Bull! A group of investigators follows 39! (7)
- 4 See 2 Down.
- 5 Arachidic formed from ionic Co/As reaction. (9)
- 6 Faculty has what it takes. (7)
- 7 Fluorine is very reactive to Ne gel treatment. (15)
- 9 Charge her. (3)
- 15 917873953ng put into the skillet. (3,6)
- 17 Needs some force to move a tinier way. (7)
- 18 Compete against watch. (7)
- 19 Orbital trace changes may be continuous or discrete. (7)
- 20 Pyrrole is not formed in a C3 Li/Y battery. (7)
- 22 Low concentration: 15 late in the day. (1.1.1)

Graham Mulroney FRACI CChem is Emeritus Professor of Industry Education at RMIT University. Solution available online at chemaust.raci.org.au, Other resources.

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