

chemistry

September–November 2020

in Australia



Fertile future for sustainable fuel

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- The pressing concern of water security
- Louis Pasteur, father of microbiology and virology
- The problem of patenting polymorphs

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cover story

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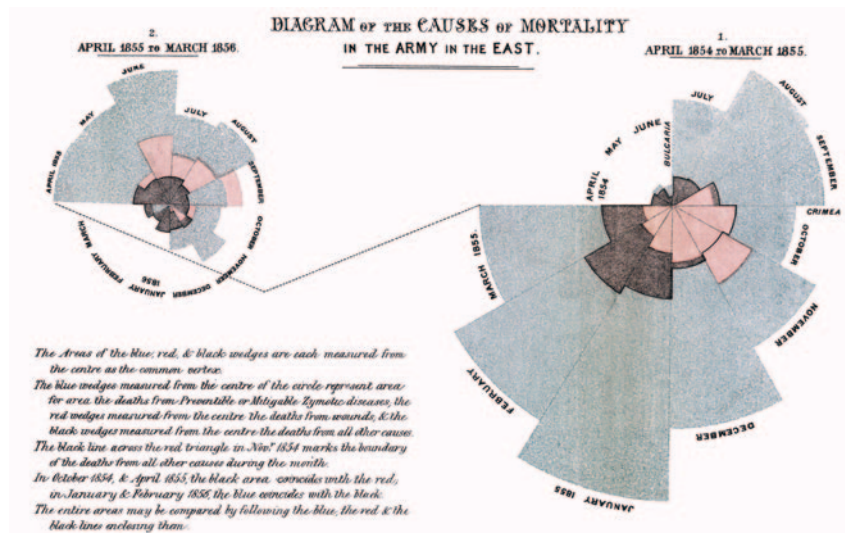
A visual treatment

This year is the World Health Organization's International Year of the Nurse and Midwife, which includes the 200th anniversary of Florence Nightingale's birth.

The familiar story goes that, working in 19th-century Turkey in a medical facility overwhelmed by sick and injured British and allied soldiers, the 'lady with the lamp' established order, greatly improving sanitation and being responsible for significant reductions in the mortality rate. Less well known is her use of visuals to push for change both during and after the Crimean War.

The years leading up to Nightingale's work in the Crimea saw some pertinent events in statistics and science. In 1837, the UK's General Registry Office began to keep systematic records of births, deaths and marriages, which made valuable statistics available. (Registrar-General William Farr would later be an important ally to Nightingale in her statistical analysis.) In 1848, across the Channel, French chemist Louis Pasteur had begun his studies, starting with crystals of tartrates, and perhaps giving the earliest demonstration of molecular chirality. You can read more about Pasteur and his work with tartrates and fermentation in Alf Larcher's feature on page 24 of this issue.

Nightingale was key adviser to Sidney Herbert, who as Secretary of War during the Crimean War sent Nightingale and a team of volunteer nurses to the Turkish barracks at Scutari. Having witnessed the horrific reality of armed conflict, she returned to Britain and began to collect evidence before a royal commission. Drawing on large amounts of war data, she was able to make a convincing case for the benefits of good sanitation. One of her visuals was a polar area diagram (pictured) to indicate sources of patient mortality during the war. This was an effective way to show that most of the men who died in



One of Florence's polar area diagrams, from *Notes on matters affecting the health of the British Army (1858)*, a confidential report prepared by Nightingale for the British Government in 1858.

that war were casualties of preventable disease, and that the death rate declined significantly when hygiene practices were implemented.

In the 1860s, surgeon Joseph Lister, after reading a paper by Pasteur on food spoilage, had proposed the use of carbolic acid (phenol) to reduce surgical infection rates, but unlike Nightingale's his data was limited and the medical fraternity was largely unconvinced, partly because germ theory was still a matter for speculation, despite ideas about it being in existence since Avicenna in the 11th century. By this time, Nightingale had founded professional nursing with her newly established St Thomas' Hospital in London.

Nightingale grew up at a time when Galen's ancient theory of 'miasma' was still a dominant idea about the origin of disease. However, many sources suggest that she discarded this idea in favour of germ theory. It is thought that initially she believed that soldiers were dying in the Crimea due to poor nutrition and overwork, but that her subsequent data

collection for the royal commission changed her view. In a chapter she wrote in the late 1870s for *Quain's medical dictionary*, Nightingale advised antiseptic precautions:

Always have chlorinated soda for nurses to wash their hands, especially after dressing or handling a suspicious case. It may destroy germs at the expense of the cuticle, but if it takes off the cuticle, it must be bad for the germs.

If you haven't visited already, reddit's Data Is Beautiful ([reddit.com/r/dataisbeautiful](https://www.reddit.com/r/dataisbeautiful)) is worth a look. It's a data-lover's dream. Alongside the copious quantities of COVID visuals are subgroups with themes for infographics, word clouds, maths and charts. Browse through the selection to find out such gems as what percentage of *Hey Jude's* lyrics were 'na', or make your own, more useful, visual.



Sally Woollett
(editor@raci.org.au)

Saving *Chemistry in Australia*

It was with great regret that I learnt *Chemistry in Australia* will become a quarterly magazine (July/August, p. 4).

I have no doubt the management committee was asked to explore a multitude of options that might allow the magazine to continue to be published more frequently. However, before reducing *Chemistry in Australia* to a quarterly publication, it would have been beneficial if the RACI Board had chosen to share the reasons for their drastic action with the magazine's readers.

It is not my intention to undermine the Board's decision, because I can understand that when faced with a significant financial shortfall, they might respond in the classical way – by cutting costs and raising prices. Unfortunately, their unilateral decision does not necessarily reflect what the RACI membership expects. And that should not be ignored.

When Ann Mikhelson took over from me as editor of *Chemistry in Australia* in 1985, one of the first actions she took was to carry out a survey of readers (Mikhelson A. *Chem. Aust.* 1986, vol. 53, p. 332). It found in that year, '99% of members read the magazine' and '76% rated it as a moderately to very important part of their subscription'. I think that the response was remarkably clear and positive. But, of course, that was 34 years ago.

By all means, try the quarterly magazine option. But at the same time, conduct another survey of readers, to discover what they expect in 2020. The survey should include two more questions: 'What is the optimum number of issues of the magazine readers would like to receive each year?' and 'How many readers would now be happy to receive and read an electronic version of the magazine?'

The Committee also needs to urgently identify more paid advertising for the magazine and it is imperative the Board continues to promote expansion of the membership of the Institute, perhaps with more incentives. Both will contribute to *Chemistry in Australia's* survival.

Peter G. Lehman FRACI CChem

Reply from the CEO

Chemistry in Australia is recognised by the RACI Board as a valuable member benefit to a cohort of RACI members; however, the demand for the magazine is nowhere near the levels it was in Ann Mikhelson's period, and in this time of financial hardship a cost-benefit approach is needed.

Today, only 20% of the membership is willing to pay for a physical copy of the magazine even though the cost, at just over \$3 an edition, is minimal.

With the online edition, the take-up is worse, with a smaller number of users accessing the magazine than those who purchase it.

The bottom line is the percentage of members who regularly view the magazine is less than 40%.

This low readership has a detrimental effect on the magazine's attractiveness as an advertising medium to the commercial world. The advertiser's goal is to reach as many potential customers as possible and most advertisers do not believe the reach of the magazine warrants their using it as an advertising vehicle. Currently, we only have two regular advertisers. We have recently employed a new marketing specialist and one of their key tasks is to market the magazine to potential clients.

Creating the online platform, charging a token amount for the hard copy and reducing the number of editions over the past four years has reduced the magazine's cost to the RACI by 60%, but this still represents a significant amount and the Board took the prudent decision in this financially difficult time to move to a quarterly edition. If advertising improves and the financial position strengthens, then the decision can be revisited.

Roger Stapleford CEO RACI

Editor's note: This September–November issue is the first of our quarterly publications. The new month spans are on a seasonal basis, with the aim to publish highly relevant content (such as Nobel Prize news) in as timely a manner as possible.

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Remembering nomography

Nomography is a process of graphical representation of mathematical relations, best known to scientists and engineers of mostly mature age, it having become largely eclipsed by computers within historic times, i.e. since the 1970s!

Ben Selinger recently referred to nomographs (or nomograms or alignment charts as they are variously named) (July/August, p. 24). He has now suggested that it would be useful to draw readers' attention to some very useful and informative online blogs of their usefulness and wide application by Ron Doerfler, a principal proponent of and expert in nomography (bit.ly/3eNrX8M, bit.ly/2E8fJLe).

Although nomographs may be regarded as obsolete, they can be of considerable service in situations requiring reliable results with urgency, as in clinical situations, or for repeated data survey over a range. They illustrate relations rather than providing 'black box' numbers. They are not subject to misplacement of decimal points in a calculator, mistaken application of formulas, software obsolescence, poor or absent electronic communication access, temporary loss of power, or absence of power in remote locations.

Some chemical examples are contained in a paper that I have co-authored with Ron Doerfler (*Int. J. Math. Educ. Sci. Technol.* 2019, vol. 50, pp. 1273–84.), viz, gas expansion for hot-air balloonists, solvent boiling points under vacuum for chemical laboratories, relative centrifugal force for sedimentation studies, and body-mass index for clinical drug-dosing.

Leslie Glasser MRACI CChem



Understanding the registration process

Ben Selinger rightly points out the huge challenge that the APVMA faces in approving registrations of agricultural and veterinary chemicals (July/August, p. 5). Yet there is a highly rational, rigorous process that supports *optimising* 'the greatest good for the greatest number', aiming to guarantee effectiveness in application while providing safety in food production, even if some compromises are needed.

In our experience, from field testing the environmental behaviour of new products, the APVMA does not allow manufacturers any slack – explaining the high costs from laboratory to the market they must bear. In this process, principles of chemistry and biochemistry are paramount, from ease of chemical analysis, environmental and human toxicology, quantitative risk assessment using probabilistic methods, and ability to perform confirmatory monitoring in the field. True, many lessons were learned while these processes were improved. But it is ironic that the most excellent of these cases in terms of meeting all the criteria, glyphosate, has become so contentious. Despite its most excellent chemistry, it is disappointing that green political opposition to genetic modification and some avarice from legal firms is raising insurance costs for all, without just cause or useful remedy for human health – nor contributing to affordable food production. Still, we do need a more diverse range of products as good as glyphosate.

I support Ben's call for a better public understanding of the registration process, promising that young chemists who prefer the exercise of reason over emotion can be rewarded by gainful employment in this obviously multidisciplinary area. In fact, it can be fun! I also encourage university researchers and teachers to take an active interest.

Ivan Kennedy AM, FRACI CChem

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BASF calculates CO₂ footprint of all sales products

BASF will provide its customers with total values of CO₂ emissions ('carbon footprints') for all of its products. The Product Carbon Footprint (PCF) comprises all product-related greenhouse gas emissions that occur until the BASF product leaves the factory gate for the customer: from the purchased raw material to the use of energy in production processes.

BASF has been calculating PCFs for individual products since 2007. With the digital solution developed in-house, BASF will be able to calculate the PCF for its approximately 45 000 sales products based on a global level. BASF will start with selected product and customer segments and plans to make PCF data available for the entire portfolio by the end of 2021.

One example is BASF's biomass balance approach, in which fossil resources are replaced by renewable raw materials from organic waste and vegetable oils in the production Verbund site and mathematically allocated to the sales product. Another example of the application of the mass balance approach is the ChemCycling™ project. Since 2020, BASF has been offering its customers the first commercial quantities of products that are produced from chemically recycled plastic waste as a raw material at the beginning of the value chain. BASF's sales products from both approaches have the same properties as products based on purely fossil raw materials – but with a lower carbon footprint.

Climate protection is an important part of BASF's strategy. BASF has set itself the goal of keeping production-related

emissions constant until 2030 despite further growth. BASF is pursuing a three-pronged approach consisting of increasing its production and process efficiency, purchasing electricity from renewable sources and developing fundamentally new and low-emission processes.

Comparable standards necessary

BASF has been using sustainability assessment methods for 25 years. This includes the collection and processing of data for the measurement of sustainability contributions, as is currently used, e.g. in SEEBalance® or Sustainable Solution Steering. BASF's PCF calculation is based on substantial data from the collection of emissions in its own production network and high-quality average data for purchased raw materials and purchased energy. The methodology follows general standards for life-cycle analysis such as ISO 4044 and ISO 14067 as well as the Greenhouse Gas Protocol Product Standard.

BASF is committed to the introduction of product-specific guidelines for the calculation of PCFs in the chemical industry in order to create an industry-wide level playing field and comparability for products. 'We are working with various partners to promote standardisation', says Christoph Jäkel, Head of Corporate Sustainability.

For more information, visit www.basf.com.

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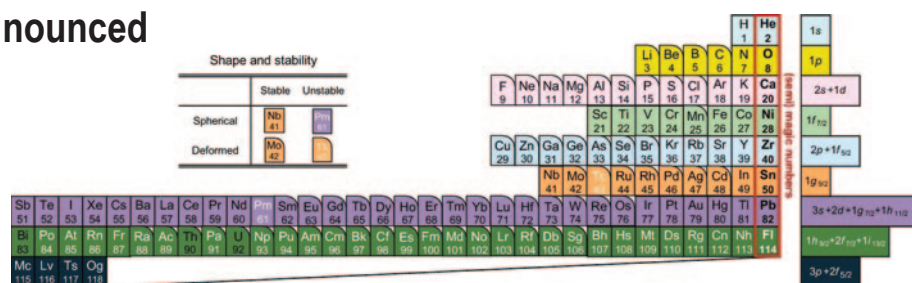


'Nuclear' periodic table announced

Physicists from Kyoto University have unveiled a new periodic table that provides a different perspective on the building blocks of the universe. While the traditional table is based on the behaviour of electrons in an atom, this new table is based on protons.

The team's new Nucleotouch table – also available as a 3D model – was announced recently in *Foundations of Chemistry* (doi.org/10.1007/s10698-020-09365-5).

The principle of atomic 'magic numbers' of the noble gases can also be applied to protons. Imagining that protons in a nucleus exist in orbits may seem like a stretch, but the discovery of the concept was awarded the 1963 Nobel Prize in Physics.



The nuclear periodic table is based on atomic 'magic numbers'. Springer

Protons have different stable magic numbers: 2, 8, 20, 28, and so on. The Nucleotouch table places these 'magic nuclei' of protons at its centre, providing a new perspective on the elements.

'Similar to electrons, when nuclear orbits are filled with protons, they form stable nuclei, analogous to the noble-gas elements', said collaborator Kouichi Hagino.

'In our nuclear periodic table, we also see that nuclei tend to be spherically shaped near the magic numbers, but deformed as you move away from them.'

The team made the table to highlight alternative ways to illustrate the laws of nature, and hopes that enthusiasts and academics alike will learn something from this fresh new look at an old friend.

Kyoto University

Estimating bisphenol exposures

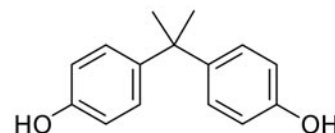
Once found in bottles, food containers, cash register receipts and electronics, bisphenol A (BPA) has been phased out of many products because of health concerns and government regulations. As a result, the production and use of BPA analogues, which are unregulated and poorly understood, have increased. Now, by analysing urine samples and wastewater, researchers report in *Environmental Science & Technology* how human exposure to bisphenols has changed over time in an Australian population (doi.org/10.1021/acs.est.0c00921).

BPA is used in the manufacture of polycarbonate plastics and epoxy resins. An endocrine disruptor, the compound readily leaches from these products, and high levels have been linked to health problems in humans and laboratory animals. With increasing regulation and unfavourable public opinion, BPA is being replaced with similar compounds, such as bisphenol S (BPS), bisphenol F (BPF), bisphenol B (BPB) and bisphenol AF (BP-AF). However, these compounds have not been well studied, and despite their similar chemical structures to BPA, they are largely unregulated. Chang He and colleagues wanted to use pooled urine samples and wastewater collected from

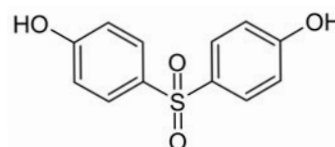
south-east Queensland to estimate exposure to various bisphenols over a six-year period.

Between 2012 and 2017, the team collected urine samples from a pathology lab and wastewater samples from three wastewater treatment plants. For each two-year period, they pooled urine samples from the lab by age and sex so that they could determine average levels of bisphenol exposure. Using liquid chromatography/tandem mass spectrometry, the researchers detected BPA in all pooled urine samples, and BPS in 97% of samples, whereas BPB, BPF and BP-AF were not found in any samples. Over the years, urinary levels of BPA decreased, while BPS levels increased. Higher levels of BPA were measured in younger age groups, which might reflect the presence of BPA in many children's products, such as bottles and toys, manufactured in Australia before 2010. In wastewater, BPA and BPS were detected in all samples, and BPF in 29% of samples. The levels of these bisphenols in wastewater were much higher than predicted from urinary excretion, indicating that most of the compounds arose from leaching from plastic products, industrial input or other sources.

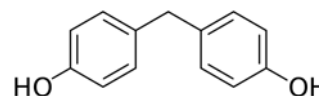
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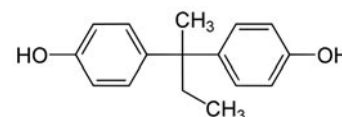
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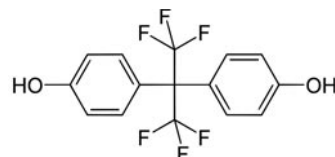
Bisphenol S Wiki/Roland1952



Bisphenol F Wiki/Yikrazuul



Bisphenol B Wiki/Yikrazuul



Bisphenol AF Wiki/Yikrazuul

Tracking COVID-19 in plane and cruise ship wastewater



Dr Warish Ahmed in his CSIRO laboratory at Brisbane's Ecosciences precinct.

As Australia considers how to safely welcome international visitors again, testing wastewater systems on long-haul planes and cruise ships could provide crucial information on detecting the presence of the COVID-19 virus in incoming passengers.

A paper in the *Journal of Travel Medicine* reported that testing of aircraft and cruise ship wastewater upon arriving at their destination had detected genetic fragments of the COVID-19 virus, SARS-CoV-2, a step forward in using this test

as an additional public health management tool (bit.ly/30tlifr).

Researchers from the University of Queensland and CSIRO worked with transport companies to test on-board wastewater from lavatories.

CSIRO Chief Executive Larry Marshall said rapidly pinpointing hotspots for COVID-19 will help keep all Australians safe as we start to travel again.

'Responding to a pandemic is not just about the race for a vaccine, Australian science is supporting our economic

recovery by delivering for partners like Qantas', Marshall said.

Paper co-author and Professor Jochen Mueller from the Queensland Alliance for Environmental Health Sciences (University of Queensland) said this tool could help as governments and transport industries develop plans to minimise transmission associated with resuming international travel.

'This could provide additional peace of mind to track and manage infection and play an important role in opening up long-haul flights or cruises resuming', Mueller said.

The test provides an early warning of infection, as the virus sheds in the stools of infected passengers even before they show

symptoms.

Lead author and CSIRO researcher Warish Ahmed said the virus fragments in the wastewater were unviable, so not infectious.

'The study indicates that surveillance of wastewater from large transport vessels with their own sanitation systems has potential as a parallel data source to prioritise clinical testing among disembarking passengers', Ahmed said.

CSIRO

Survey of scientists

Professional Scientists Australia in conjunction with Science and Technology Australia have released *The initial employment impact of the COVID-19 pandemic on Australia's science workforce* report 2020.

A survey of more than 1400 Australian scientists found that nearly one in four scientists said anxiety and mental distress due to the pandemic was affecting their ability to work.

Professional Scientists Australia has called for stronger investment in the science and technology workforce as part of economic reconstruction efforts after this survey found that Australia's scientists are being hit hard by COVID-19-related stress and job insecurity.

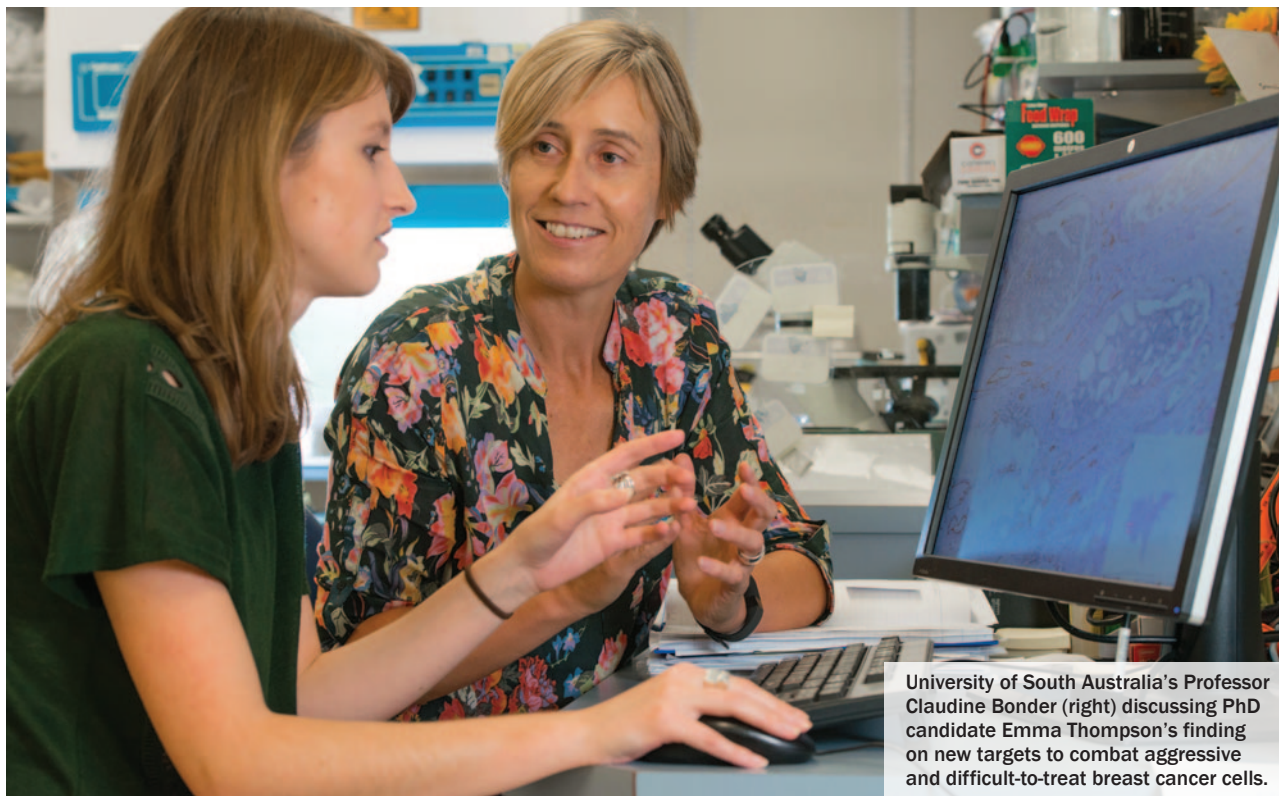
Gordon Brock, CEO of Professional Scientists Australia, said, 'As Australians look to their scientists to protect them in the battle against COVID-19, our scientists

are struggling with challenges on multiple fronts. Not only were the nation's scientists dealing with the stress and responsibility of confronting the COVID-19 pandemic, they were having to deal with multiple economic and personal issues as well.'

Download the free survey report at www.professionalsaustralia.org.au/scientists.

Professional Scientists Australia

L'Oréal adopts South Australian mentoring tool



University of South Australia's Professor Claudine Bonder (right) discussing PhD candidate Emma Thompson's finding on new targets to combat aggressive and difficult-to-treat breast cancer cells.

Mentoring is often considered an essential element in a successful post-PhD career with many a savvy-starter getting sage advice from an experienced other. However, nailing down the true value of mentoring, from an industry perspective, has been much more elusive, until now.

In an Australian first, the University of South Australia's in-house mentoring evaluation tool will address this challenge as L'Oréal Australia and New Zealand adopts the tool to enhance and monitor its PhD mentoring program as part of the L'Oréal-UNESCO For Women in Science program.

The UniSA Mentoring Impact Evaluation tool is the only longitudinal evaluation tool for PhD mentoring in Australia and this will be the first time it will be applied in a commercial environment.

Chief developer, University of SA's Associate Head and Manager Graduate Research Development Claire Jackson says she is excited to see the tool applied to the corporate environment.

'Initially we developed the Mentoring Impact Evaluation tool to measure the effectiveness of mentoring programs on PhD employability', Jackson said.

'Following its inaugural use to evaluate the government-supported Industry Mentoring Network in STEM (IMNIS) scheme, we were very pleased to see it adopted by all three South Australian universities, as well as universities in New South Wales.

'The beauty of our mentoring tool is that it has the capacity to measure mentees' skills and knowledge development across the entire mentoring journey. We collect and monitor progress pre, mid and post the experience, so we're really delivering a 360° view.

'Importantly, the universal design of the tool means that it can be adopted for any longitudinal industry experience, and given the need to boost women in STEM, we're so pleased that L'Oréal is adopting our product for their For Women in Science mentoring program.'

The L'Oréal-UNESCO For Women in Science program (FWIS) promotes and

highlights the importance of ensuring greater participation of women in science, with the program awarding exceptional female scientists at different stages of their careers with fellowships to help further their research. Part of this is a mentoring scheme where the current FWIS Fellows mentor passionate and ambitious PhD students.

L'Oréal Australia's Communications Director, Christine Burke, says mentoring plays a vital role in inspiring and instilling confidence to women in STEM, especially during the early stages of their careers.

'Female role models and champions of change are ideal mentors to share advice and guidance to budding female scientists,' Burke says.

'Being able to quantify the impact of mentoring and how it can deliver ongoing and significant benefits for the mentee and mentor, but also the business, is an essential step to formalising this much-valued practice for women in STEM.'

University of South Australia

Diversity in science ‘crucial’: essay

Nobel laureate and University of NSW SHARP Hire Sir Fraser Stoddart and University of NSW Chemistry Professor Palli Thordarson FRACI CChem are co-authors of an essay that is published simultaneously by six scientific journals (see go.nature.com/3lflhA0).

The essay, ‘Catalyzing change – a diverse view of science’, is a collaboration between 30 chemists from different countries. It examines the way some scientists have been marginalised and makes an impassioned case for building an inclusive scientific community based on mutual respect.

The piece places the onus on each and every member of the scientific community to remember and respect the fundamental human qualities of their colleagues, and it emphasises how easy it can be for scientists who find themselves in the social mainstream to underestimate, misunderstand or simply overlook the challenges posed by marginalisation.

Co-author Stoddart, who shared the 2016 Nobel Prize for his work on the design and synthesis of molecular machines and joined the University of NSW in 2017 as part of the university’s Strategic Hires and Retention Pathways (SHARP) scheme, says diversity is crucial.

‘We’re all Jock Tamson’s Bairns’, he says, summoning a traditional Scottish assertion that humanity is shared by one and all. He explains that an acceptance of mutual respect was part and parcel of growing up in rural Scotland, although much of his career has been spent struggling with individuals and institutions operating on the entirely opposite tack. Now that he is in an esteemed position to cultivate this virtue in a new generation, he is more convinced than ever of just how precious and important such initiatives are.

‘Diversity makes it possible to do things that you could not conceive of otherwise’, he says. ‘I know it works.’

Co-author Thordarson says diversity is about leading by example.

‘Diversity is really about being decent – treating no person unfairly just because of what they are. If we all stop for a moment and reflect on that, we could go much further again. The problem is that our culture(s) still have many hangovers from times when it was acceptable to treat people unfairly due to some of the characteristics that made them unique.’

Thordarson says while you can’t ‘force’ people to accept diversity, education and motivation could work.

‘This is why leadership is so important’, he says. ‘A leader that is truly committed to diversity can motivate those around them to follow. We all can do this. We need to recognise our own weaknesses, mistakes and prejudices and then lead by example.’

Dr Michael Bojdys, who leads a research group at King’s College London, was among a handful of primary authors who assembled the article over the course of just a few weeks, a team that included fellow academics and students in North America and Europe.

‘This piece spoke for itself, it did not take too much convincing’, he says. ‘If people are not willing to follow the moralistic arguments, that this piece is timely and important, then they would at the very least have followed the bottom line, which is that it will generate traffic.’

Above all, he points out, the authors worked hard to strike a tone of progress and cooperation, as opposed to confrontation. ‘We would speak the language of a positive outlook, how science and academia could be’, he says. ‘This is what won people over, ultimately.’

UNSW Science is committed to championing equity, diversity and inclusion (EDI), and aims to provide an equitable place of work and study that will stimulate innovation, productivity and progress.

The essay ... examines the way some scientists have been marginalised and makes an impassioned case for building an inclusive scientific community based on mutual respect.

‘We believe diversity and inclusion are essential to our success, helping to produce robust, credible and pioneering science of global impact and train the next generation of scientists’, says Professor Sarah Brough, who co-chairs the Faculty’s EDI Working Group.

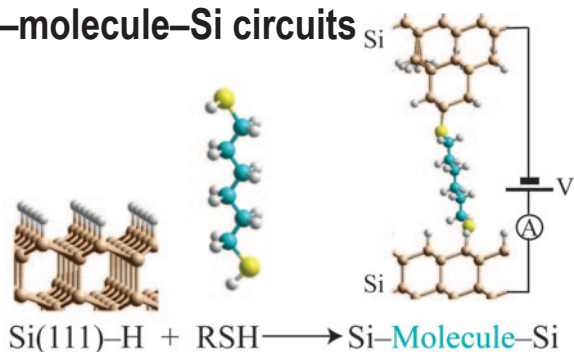
‘We’re committed to reducing barriers which impede equity, diversity and inclusion via initiatives that will benefit both staff and students. For example, our Women in Maths and Science Champions Program – a 12-month career development program to support our female research students and early career scientists to become science professionals – provides women within UNSW Science with the skills and confidence to build their public profile and make a positive impact on the broader science community.’

This year – with many staff having been affected by the Australian bushfires in 2019–2020 and COVID-19 in 2020 – UNSW Science also released guidelines for achievement relative to opportunity.

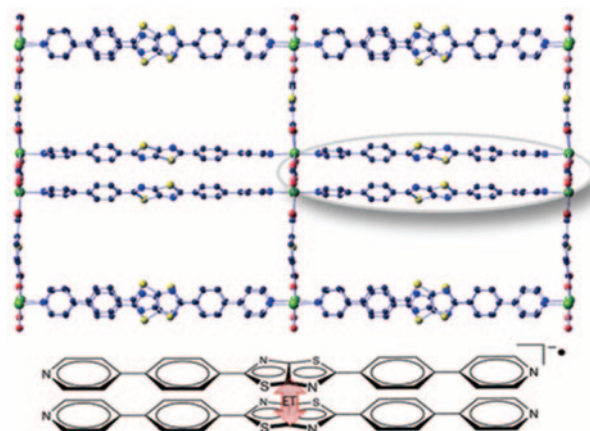
‘We wanted to acknowledge that many staff are experiencing more substantial additional responsibilities and experiencing some of the adverse effects of working remotely and/or in isolation’, Brough says. ‘We want to enable staff to have these impacts considered when discussing achievements they have made during this time.’

University of New South Wales

Si-molecule-Si circuits



The ultimate goal in molecular electronics is to use individual molecules as components in devices, since single molecules constitute the smallest possible stable structures and could be key to miniaturising devices beyond Moore's law. Until now, however, single-molecule circuitry has not been mechanically stable, has been largely restricted to highly specialised laboratories using expensive materials such as gold, and has been fabricated mostly at extremely low temperatures that are not viable for industrial scale-up. Turning single-molecule circuitry into a translatable technology requires compatibility with currently used silicon-based platforms. Recently, a team led by Nadim Darwish of Curtin University and Jeffery Reimers of University of Technology Sydney has achieved a significant step towards realisation of silicon-based molecular circuits (Peiris C.R., Ciampi S., Dief E.M., Zhang J., Canfield P.J., Le Brun A.P., Kosov D.S., Reimers J.R., Darwish N. *Chem. Sci.* 2020, **11**, 5246–56). The team fabricated molecular circuits between source and drain electrodes based on covalent silicon–sulfur bonding that operates under ambient conditions and without the need for chemical initiators, heating, pressure or light irradiation. These circuits are compatible with existing silicon-fabrication technologies and will enable molecular circuits that are not just small but also add versatility in being controllable by the nature of the connecting molecule, by the type of the silicon contacts, and by external stimuli such as light.



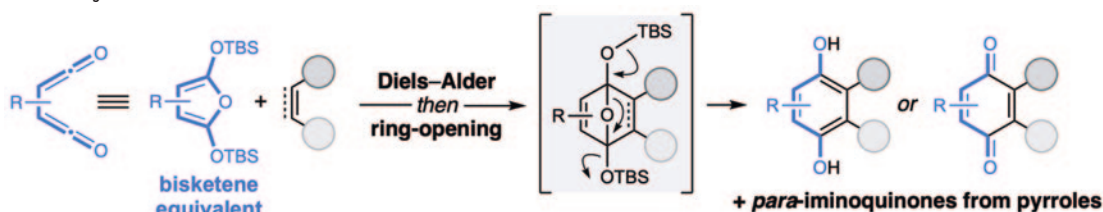
Single-crystal spectroscopy for measuring MOF charge transfer

Metal-organic frameworks (MOFs) offer an ideal platform for studying fundamental aspects of electron transfer (ET) in three-dimensional coordination space owing to their highly ordered nature and tunability, which opens up opportunities to explore structure–activity relationships. Previous work from the D'Alessandro group at the University of Sydney has demonstrated that frameworks containing 'cofacially aligned' ligands – akin to double-glazed windows in buildings – undergo a rare through-space charge transfer upon electrochemical reduction (see e.g. *J. Am. Chem. Soc.* 2018, **140**, 6622–30; *Chem. Sci.* 2019, **10**, 1392–400). A major challenge in these studies has been how to quantitatively assess the charge transfer using spectroscopic data. In their latest work, the group has applied a single-crystal spectroscopic method to enable the key parameters, including the rate constants for electron transfer, to be quantitatively determined (Doheny P.W., Clegg J.K., Tuna F., Collison D., Kepert C.J., D'Alessandro D.M. *Chem. Sci.* 2020, **11**, 5213–20). This new protocol provides a simple method that can be applied widely to examine charge-transfer phenomena in MOFs and other solid-state materials that have potential in applications in porous conductors, electrocatalysts and energy-storage devices.

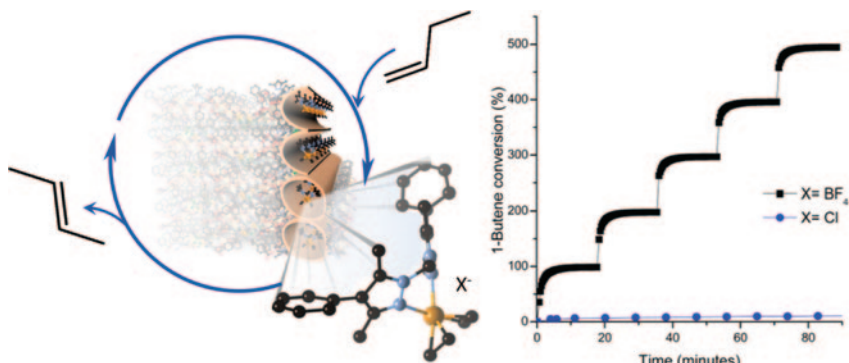
Diels–Alder approach to *para*-quinones

The *para*-(hydro)quinone motif features in a large number of biologically active natural products. Complex derivatives can often only be prepared in small quantities via lengthy multi-step sequences, impeding efforts to leverage targets in applied settings. A team led by Christopher Newton at the University of Adelaide has recently developed a one-pot Diels–Alder methodology for accessing highly substituted *para*-quinones in a highly convergent manner (Dissanayake I., Hart J.D., Becroft E.C., Sumby C.J., Newton C.G. *J. Am. Chem. Soc.* 2020,

142, 13 328–33). Central to realising the transformation was the development of a bisketene equivalent that is sufficiently stable to be handled without specialised techniques, while also remaining primed for a facile ring-opening event. The generality of the approach was demonstrated through the preparation of several *para*-hydro-, benzo- and imino-quinones, including a gram-scale synthesis of a neuroprotective *para*-hydroquinone-containing natural product.



Efficient porous catalyst for alkene isomerisation



Metal–organic frameworks (MOFs) possess unique attributes, including permanent porosity, large internal surface areas and robust crystallinity. These attributes have motivated interest in the field of gas-phase catalysis, where MOFs can act as a platform for the heterogenisation of molecular catalysts, allowing easy catalyst recovery and structural elucidation of the

active centres involved in catalysis. Recently, researchers at the University of Adelaide have used a bespoke MOF, MnMOF-1, to trap and study an alkene isomerisation catalyst (Peralta R.A., Huxley M.T., Evans J.D., Fallon T., Cao H., He M., Zhao X.S., Agnoli S., Sumbly C.J., Doonan C.J. *J. Am. Chem. Soc.* 2020, **142**, 13 533–43). Heterogenisation of the

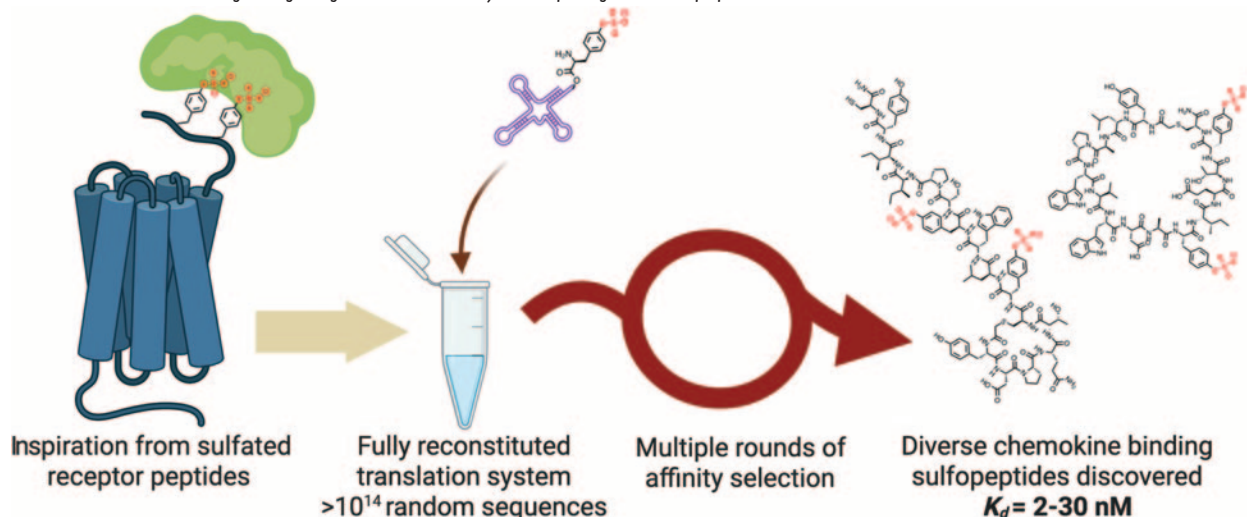
catalyst was achieved via post-synthetic metallation and anion exchange to give catalytically active Rh^I centres anchored within the MOF pores. The structures of these MOF-tethered Rh^I bisethylenediamine complexes, MnMOF-1 · [Rh(C₂H₄)₂]BF₄ and MnMOF-1 · [Rh(C₂H₄)₂]Cl, was determined by X-ray crystallography and their activity for gas-phase butene isomerisation was then studied by gas-phase NMR spectroscopy. MnMOF-1 · [Rh(C₂H₄)₂]BF₄ rapidly catalyses the conversion of 1-butene to 2-butene with a turnover frequency of around 2000/hour at 1 bar and 46°C. In contrast, the chloride derivative, MnMOF-1 · [Rh(C₂H₄)₂]Cl, displays negligible activity. Spectroscopic data and computation suggest that a strong interaction between the chloride anion and the Rh centre impedes the reactivity.

Rapid route to anti-inflammatory drugs

Chemokines are small proteins that direct trafficking of white blood cells to sites of inflammation and are attractive therapeutic targets for inflammatory disorders. Tyrosine sulfation is an important post-translational modification that drives chemokine–receptor binding and is also incorporated into pathogenic chemokine-binding proteins to improve chemokine binding affinity and evade the host immune response. Recently, researchers at the University of Sydney

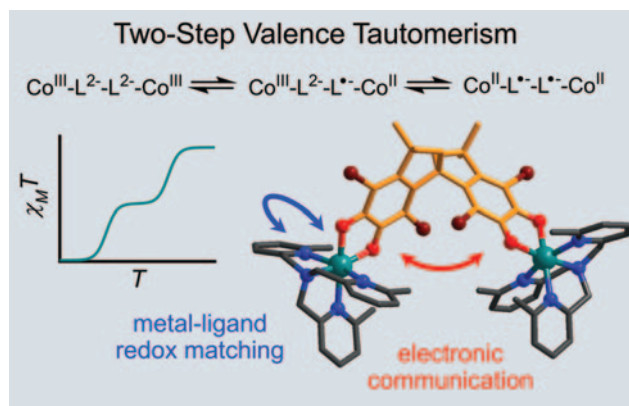
have used mRNA display under a reprogrammed genetic code to display large libraries (>10¹⁴) of sulfated cyclic peptides, which were selected for binding to the chemokine CCL11 with a view to discovering novel lead molecules for the treatment of allergic inflammation (Johansen-Leete J., Passioura T., Foster S.R., Bhusal R.P., Ford D.J., Liu M., Jongkees S.A.K., Suga H., Stone M.J., Payne R.J. *J. Am. Chem. Soc.* 2020, **142**, 9141–6). Multiple cyclic sulfopeptides were

discovered with nanomolar affinity for CCL11 as well as to other proinflammatory chemokines with shared pro-inflammatory roles to CCL11 in vivo. The discovered peptides effectively inhibited chemokine–receptor binding and signalling in cells and displayed good plasma stability. The display platform presents an effective and expedient method to rapidly discover novel anti-inflammatory lead molecules for drug development.



Multi-switchable molecular materials

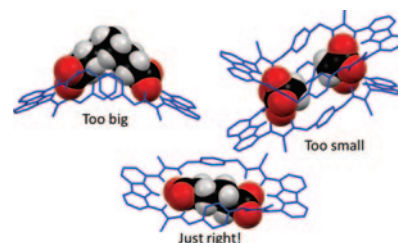
Molecules that can be reversibly switched between three or more states are potentially useful for complex logic processes in molecular electronics and spintronics, ternary computing and multi-switchable displays. Dinuclear Fe^{II} complexes that exhibit two-step spin crossover are at the forefront of this area. But transitions in these species are directed by local electronic effects, which are difficult to control and allow little prospect of chemical tuning. A team led by Colette Boskovic at the University of Melbourne, in collaboration with researchers from Colorado State University (USA) and the Southern Federal University (Russia), has recently reported a significant breakthrough (Gransbury G.K., Livesay B.N., Janetzki J.T., Hay M.A., Gable R.W., Shores M.P., Starikova A., Boskovic C. *J. Am. Chem. Soc.* 2020, **142**, 10 692–704). A concerted experimental and computational study of bis(dioxolene)-bridged dinuclear Co complexes confirmed weak intramolecular electronic communication as the origin of two-step valence tautomeric transitions between three electronic states ($\{\text{Co}^{\text{III}}\text{-L}^2\text{-L}^2\text{-Co}^{\text{III}}\} \rightleftharpoons \{\text{Co}^{\text{III}}\text{-L}^2\text{-L}^{\bullet}\text{-Co}^{\text{II}}\} \rightleftharpoons \{\text{Co}^{\text{II}}\text{-L}^{\bullet}\text{-L}^{\bullet}\text{-Co}^{\text{II}}\}$). These systems offer excellent possibilities for chemically tuning the interconversions. This study has delivered a comprehensive understanding of the parameters that control the stepwise nature of the transitions, which will facilitate the design of future multiswitchable molecular materials.



Goldilocks effect in dicarboxylate binding

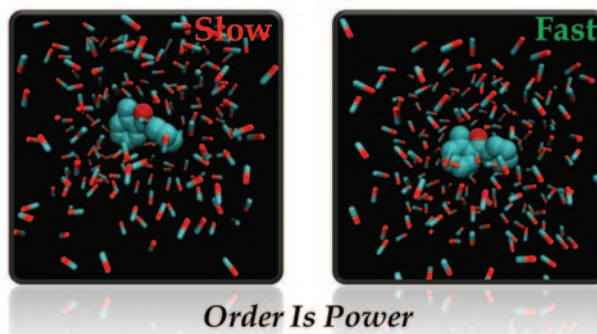
Molecular sensors that can readily distinguish between structurally similar dicarboxylate ions, such as succinate and glutarate, have potential applications in biology and industry. But the selective discrimination of these anionic species is challenging, even for the best supramolecular chemist: nature! Tailoring the shape and size of the receptor to match the guest of interest is key to strong and selective binding, but some receptor flexibility has been demonstrated to be useful to overcome

slight geometric mismatches. Optimising the role of chelate cooperativity provides a further means by which to achieve selective binding of ditopic guests. Using two conformationally flexible macrocyclic tetrathiourea receptors, researchers from the University of Sydney have investigated the effect of chelate cooperativity for binding of dicarboxylates in aqueous media (Berry S.N., Qin L., Lewis W., Jolliffe K.A. *Chem. Sci.* 2020, **11**, 7015–22). The macrocycles were found to adapt their



shape to accommodate guests of different sizes, but if the fit between host and guest was not good, negative cooperativity was observed. When the geometries of the macrocycle and guest were well matched, positive cooperativity led to high binding affinities and selectivity.

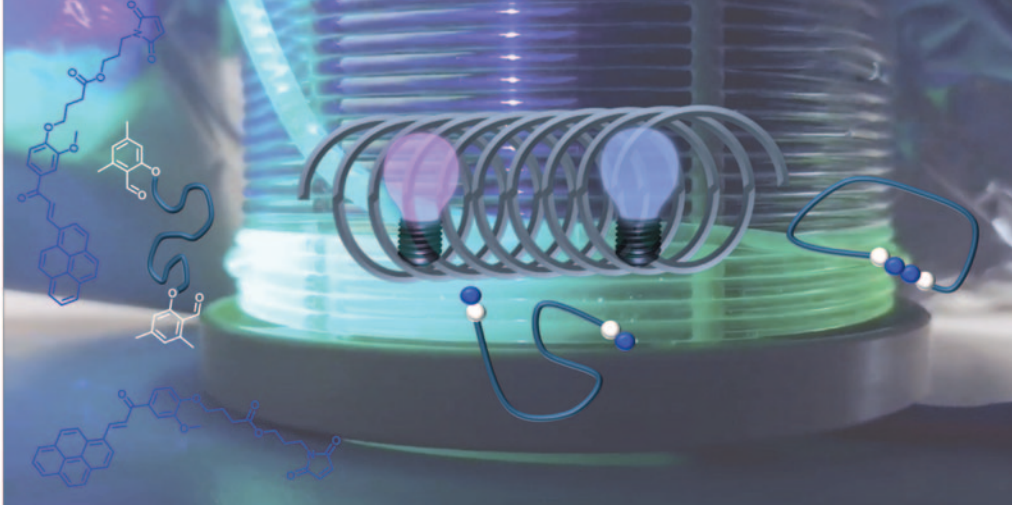
Electrostatic catalysis by solvent ordering



External electric fields have recently been shown to catalyse chemical reactions (Aragonès et al. *Nature* 2016, **531**, 88–91), but scaling these effects in practical experimental systems has been elusive to date. Now researchers from the Australian National University and Monash University have shown that ordered solvent environments can provide a way forward (Xu L., Izgorodina E.I., Coote M.L. *J. Am. Chem. Soc.* 2020, **142**, 12 826–33). The work takes advantage of the ability of solvents and ionic liquids to become ordered under external electric fields and, in the case of ionic liquids, to maintain that order for some time after the field is removed. This ordered solvent environment generates its own internal electric field that can be exploited for catalysis. Using multi-scale modelling, the team showed that these ordered solvent environments can catalyse chemical reactions even after the external field is switched off. In particular, the barriers for hydrogen transfer were shown to decrease by more than 20 kcal/mol in ordered [EMIM][BF₄], an ionic liquid, compared with normal conditions. This work suggests a possible strategy for scaling electrostatic catalysis by applying a pulsed external field to the reaction medium to maintain solvent ordering, while allowing the reaction to proceed largely in the absence of an external field.

Making light work of polymer chemistry with two-colour flow

Light-driven reactions can often be executed under catalyst-free ambient conditions and allow precise spatial and temporal control over chemical reactivity. Additionally, chemical selectivity can be achieved by simply tuning the wavelength and light intensity. Such fine control has proven to be of critical value in macromolecular design and organic synthesis. However, combining several photo-induced reactions in a multi-step sequence is a challenging task. Now, the Soft Matter Materials research team at the Queensland University of Technology has developed a λ -orthogonal system, in which two different photoreactions can

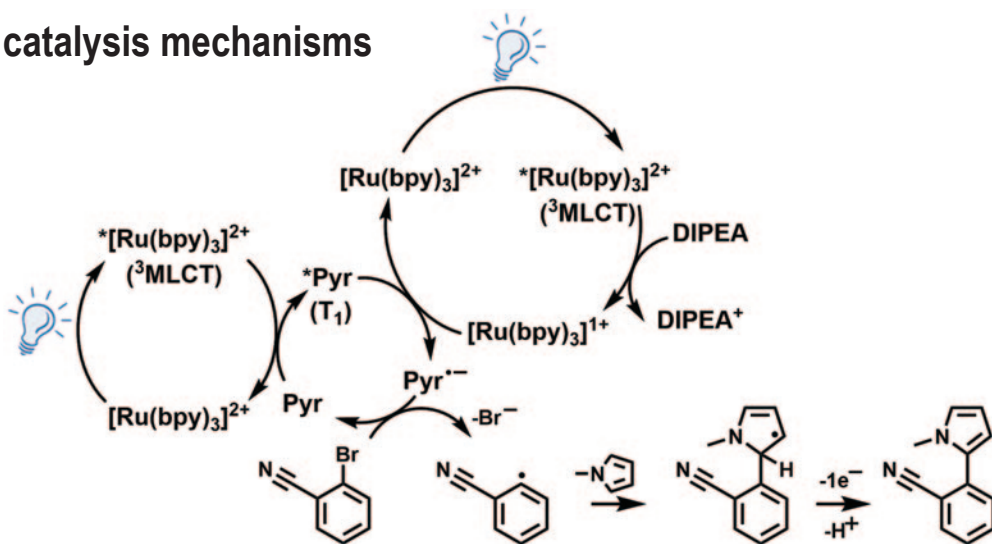


be triggered selectively in the presence of the other reaction partners (Van De Walle M., De Bruycker K., Blinco J.P., Barner-Kowollik C. *Angew. Chem. Int. Ed.* 2020, **59**, 14 143–7). The team incorporated the newly developed system into a custom-made photoflow reactor set-up, which allowed sequential irradiation with two different light

sources (with maximum irradiation at 350 and 410 nm, respectively) in two separate flow coils. The dual-wavelength-selective concept was applied on a macromolecular level, with an end group modification performed on a linear polymer in the first step, followed by an intramolecular cyclisation initiated by irradiation with the second light source.

Unravelling photoredox catalysis mechanisms

Transition-metal photoredox catalysis has facilitated the development of new synthetic organic transformations. However, the mechanisms of photocatalytic reactions can be poorly understood or even controversial. One such example is sensitisation-initiated electron transfer using $[\text{Ru}(\text{bpy})_3]^{2+}$ to sensitise the triplet state of pyrene (^3Pyr) via triplet–triplet energy transfer. It was proposed that subsequent reduction with diisopropylethylamine (DIPEA) by single-electron transfer yields the pyrene radical anion ($\text{Pyr}^{\bullet-}$), which can reduce activated aryl halides, facilitating their $-\text{CH}$ arylation. However, it was subsequently noted that this single-electron transfer reaction is highly endergonic, and an intervening triplet–triplet annihilation reaction to form ^1Pyr was suggested, for which single-electron transfer to form $\text{Pyr}^{\bullet-}$ is more thermodynamically reasonable. To settle this debate, researchers at the University

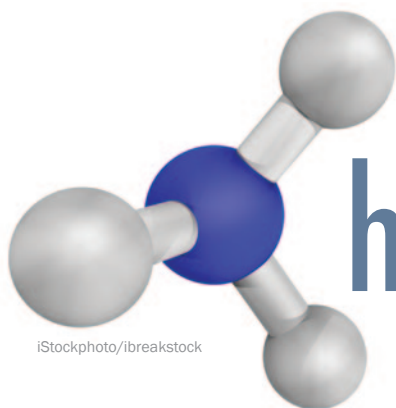


$^3\text{MLCT}$ = triplet metal-to-ligand charge transfer complex

of Queensland have investigated this reaction using time-resolved transient absorption spectroscopy (Coles M.S., Quach G., Beves J.E., Moore E.G. *Angew. Chem. Int. Ed.* 2020, **59**, 9522–6). A detailed kinetic analysis revealed that competing triplet–triplet energy transfer and single-electron transfer reactions

result in the formation of both ^3Pyr and photoreduced $[\text{Ru}(\text{bpy})_3]^+$. Moreover, these two species are sufficiently long-lived to allow their bimolecular reaction, and are responsible for generating $\text{Pyr}^{\bullet-}$, highlighting the need to consider the involvement of secondary photoproducts in photocatalytic reaction mechanisms.

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.*) are encouraged to contribute general summaries, of no more than 200 words, and an image to David.



Towards the hydrogen–ammonia economy

The race towards sustainable synthesis of ammonia is underway. Used mainly in fertilisers, this simple molecule is predicted to become a big player in renewable energy exports and energy security, as a liquid fuel replacement for fossil fuels.

BY **JACINTA M. BAKKER** AND **DOUGLAS R. MACFARLANE**

Globally, there are more than enough sustainable energy sources to supply the world's electricity demands. The issue is that sun, wind and hydropower resources are often found in rural locations and the energy is not easily 'dispatchable' as needed to cities, where demand is localised. Batteries form part of the solution but are expensive, require scarce metals for manufacture and are too heavy to represent a transportable source of large amounts of energy.

A recently emerging concept aims to store energy derived from these natural resources in the bonds of ammonia molecules. Ammonia is ideal for transport by ship or pipeline as liquefied energy (liquefies at 10 bar at room temperature or at -33°C at 1 bar; lower heating energy 5.2 MWh/tonne). Conveniently, the practice of liquid ammonia transportation is already commonplace in the fertiliser industry – 175 million tonnes were

produced worldwide for a market value of US\$70 billion in 2019, according to the United States Geological Survey (on.doi.gov/3grUUbY). So, mature technologies and infrastructure already exist to help allow this to develop.

Given Australia's massive potential in renewable energy resources, ammonia is rapidly emerging as an ideal export vector that can be readily shipped to market. As we will explain here, ammonia can thereby feed the hydrogen economies that are springing up in several countries, but has great, even surprising, potential as a fuel in its own right. In our recently published ammonia roadmap article (MacFarlane et al., doi.org/10.1016/j.joule.2020.04.004), we detail pathways towards scale-up, research progress and a multitude of direct end-use modalities, and discuss the parallel need for further understanding of the potential impacts

on the global nitrogen cycle.

Most of today's ammonia is produced by the Haber–Bosch process. Developed more than 100 years ago, it generates a very large carbon footprint, relies on fossil fuels such as methane and is efficient only at large scale in facilities that run at full capacity. We identify in our roadmap three distinct generations of technology that will move the industry away from Haber–Bosch, towards the sustainable generation of ammonia, using water, air and energy from intermittent renewable energy sources. These processes have the potential to be efficient on all scales, from a small family farm, to enormous solar- and wind-powered facilities in the Australian outback.

Although the Haber–Bosch process has been optimised over time, high temperatures and pressures ($>400^{\circ}\text{C}$ and >200 bar) are still required for efficient ammonia production. That being said, the main culprit for the

large carbon footprint is one of the starting materials: high-purity hydrogen gas, usually generated by steam-reformed methane. Currently, the Haber–Bosch process produces ammonia at an energy cost of 8 MWh/tonne and 65% energy efficiency, accounting for 1–2% of global energy consumption and more than 1% of global greenhouse gases.

Generational steps towards renewable ammonia

To improve this environmental impact, Generation 1 Haber–Bosch plants can operate with carbon capture and sequestration or the purchase of carbon credits. This represents an expensive but transitional step for the industry and infrastructure. The product is known as blue ammonia.

Generation 2 renewable ammonia refers to the product of Haber–Bosch ammonia plants being fed hydrogen that is generated by water-splitting electrolyzers, instead of steam methane reformation. Producing ‘green ammonia’, this technology, like Generation 1, avoids mothballing current Haber–Bosch infrastructure. In the UK, Siemens’ pilot plant demonstration produces 30 kilograms of ammonia per day, powered by wind energy fed to a water electrolyser (sie.ag/39XIY07). The capital cost of a proton exchange membrane electrolyser for a conventional Haber–Bosch plant is US\$1 million per megawatt but this cost is expected to decrease with further R&D. Another option is high-temperature solid oxide electrolysis, which uses waste heat from the Haber–Bosch process to split water as discussed by Danish catalysis company Haldor Topsoe (bit.ly/3fr4uKV). High-temperature solid oxide electrolysis, like a Haber–Bosch plant, is challenged by the intermittent nature of renewable energy while proton exchange membrane electrolysis is not to the same extent. Nonetheless, some form of hydrogen storage is an important requirement to smooth the

intermittency of H_2 supply into the Haber–Bosch process.

In Generation 3, the Haber–Bosch plant is no longer required and the benefits include resilience to intermittency of power supply, versatility of scale and lower N_2 purity requirements. Ammonia is produced by the electroreduction of nitrogen at a selective cathode, along with a proton source (e.g. water by oxidation at the anode) and intermittent renewable energy as the power supply. Research is currently directed to two main pathways:

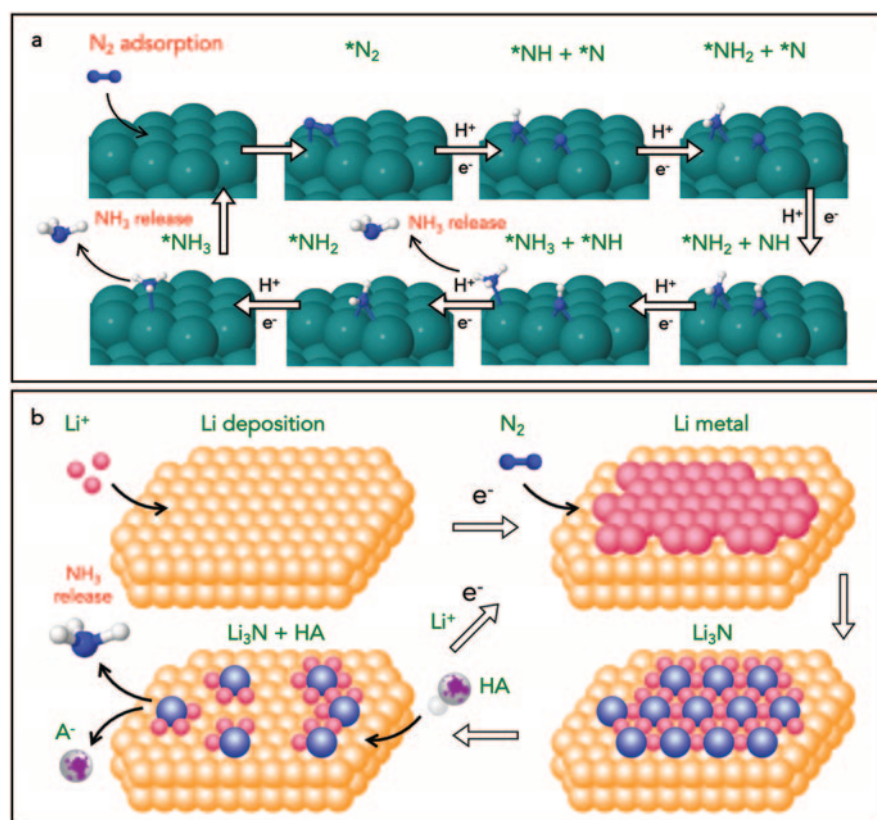
- the direct electrochemical nitrogen reduction reaction (eNRR)
- an indirect eNRR mechanism using a redox mediator.

This latter, appealing method can potentially produce ammonia at an energy cost of 15.5 MWh/tonne (NH_3)

and research effort is focused on lowering this further.

Targets and challenges of Generation 3

Reduction of the triple bond in the N_2 molecule is very difficult (hence the inert nature of N_2 gas). Researchers can easily mistake the reduction of oxidised nitrogen species such as nitrate, nitrite, N_2O and NO (collectively termed NO_x) that are ubiquitous in the atmosphere, on laboratory consumables, or from commercially supplied gas cylinders and chemical reagents for eNRR. Meticulous cleaning, purification and scrubbing procedures are required to ensure that only N_2 is present. Isotopically labelled experiments with $^{15}N_2$ and NMR studies are also crucial. To this end, we (doi.org/10.1038/s41929-019-0252-4) and other groups



Generation 3 proposed mechanisms for (a) direct eNRR (adapted from Wang et al. doi.org/10.1002/cssc.201801632), showing N_2 adsorption on to the catalyst surface followed by weakening of the triple bond and stepwise addition of 6 electrons and 6 protons to produce two equivalents of ammonia and (b) indirect redox-mediated eNRR, where Li metal reduces N_2 to form lithium nitride, Li_3N , which then reacts with a proton donor (HA) to form NH_3 and A^- while Li^+ is electrochemically reduced to regenerate Li metal, ready for further cycling. Reprinted from MacFarlane et al., doi.org/10.1016/j.joule.2020.04.004

have published protocols for conducting eNRR experiments. Unfortunately, recent peer-reviewed articles often do not include robust quality controls, leaving the literature littered with question marks and false positive results. This is particularly true of studies of aqueous eNRR systems because the yields are often low and competition from the proton reduction to hydrogen reaction is severe.

Higher ammonia yields (approaching 100 nmol/s/cm²) and Faradaic efficiency (>88%) are commonly achieved by the indirect redox-mediated eNRR method, placing this method in a more secure regime in terms of robust results.

Practical challenges of scaling up Generation 3

There are a number of practical challenges to scaling up Generation 3 approaches. Purified nitrogen starting material produced by air separation is a valuable commodity and thus separation of the produced ammonia followed by recirculation of the

nitrogen is necessary but adds capital cost.

Stoichiometrically, 1.5 tonnes of water is required per tonne of ammonia produced. Often, in areas where solar power is abundant, water is not, so this is an important consideration for large-scale eNRR. Sea water could be used directly for the supporting anode reaction either via the chlorine evolution reaction (chloride to chlorine) or remain as the water oxidation reaction (water to oxygen), which is used for Generation 2 technologies. The issue with the former is that chlorine will be produced at 20 times global demand, with obvious environmental implications. The issue with the latter is unearthing an electrocatalyst that will perform the water oxidation reaction with the selectivity and durability required under saline conditions.

Although both Generation 2 and 3 technology can operate intermittently according to the availability of renewable energy, decreasing the capacity factor will lead to an increase

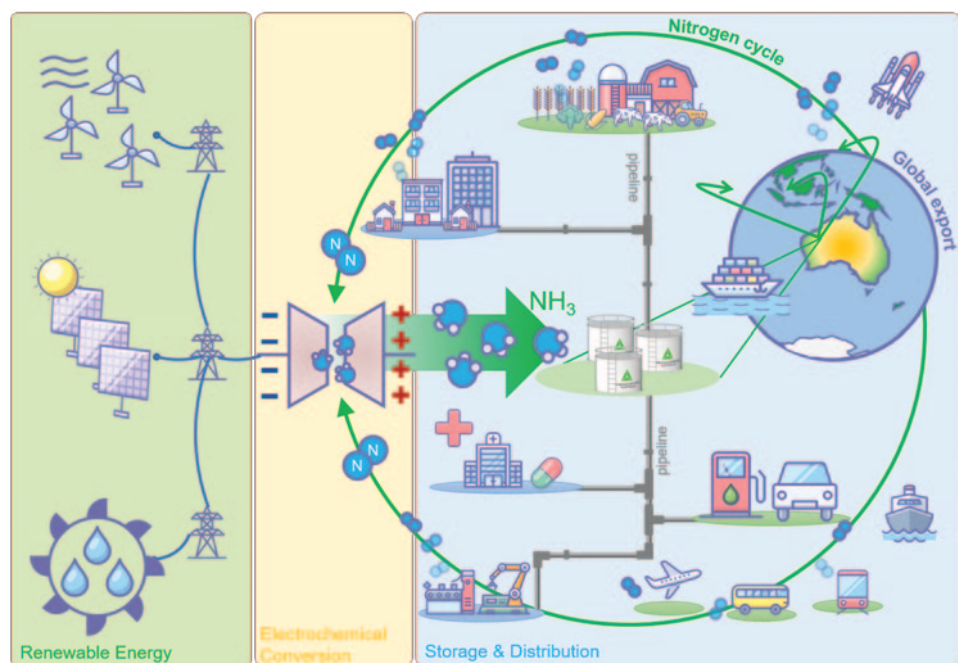
in capital cost per tonne of product. Storage of energy, whether in a battery (present cost US\$300 000/MWh stored) or as compressed hydrogen, will also increase the capital and production costs significantly.

From a social acceptance perspective, most people would immediately associate ammonia with its awful smell, which links to a perception of high toxicity. The smell can actually be viewed as a blessing in disguise: the human nose can detect ammonia at 5 ppm, which is five times lower than the concentration determined to be harmful (threshold limit value 25 ppm). Odourless gases such as hydrogen and carbon monoxide can leak undetected, resulting in increased flammability or suffocation risks. Ammonia is not classed as carcinogenic, unlike petrol. Early studies and theses advised that the risks of using ammonia as a fuel were comparable to or lower than those of liquid petroleum gas. In the maritime sector, a study determined that once mitigation strategies were in place, the risk of catastrophic failure from the use of ammonia fuel became extremely low (bit.ly/3gqE25t). Anhydrous ammonia is already transported in large amounts around the globe for the agricultural sector, and no fundamental barriers are apparent with increasing this by orders of magnitude. It is, of course, crucially important that continued research and development of procedures and standards for handling and transport take place. The Ammonia Safety Training Institute is an important leader in this sector.

End-use modalities

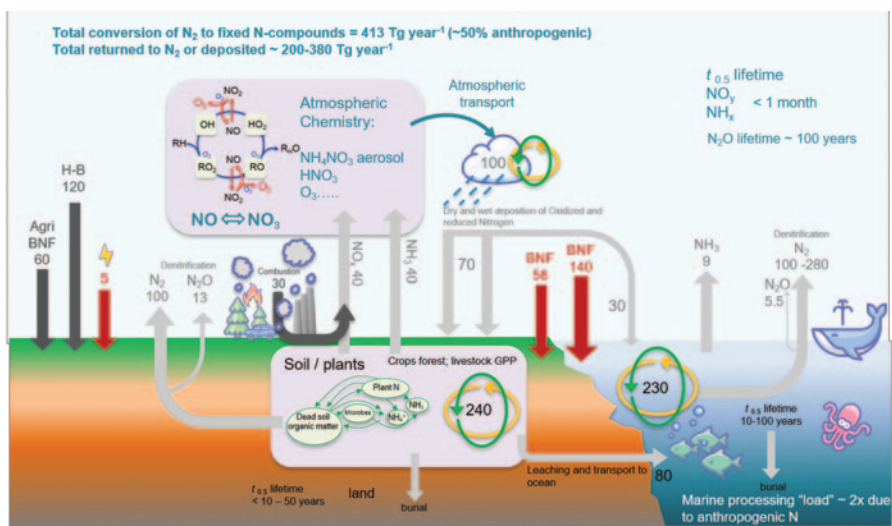
Excitingly, CSIRO has already developed the catalysts to crack ammonia into nitrogen and hydrogen gas for use in the hydrogen economy. In this sense, the ammonia and hydrogen economies overlap in synergistic ways.

On the other hand, ammonia has the potential to be used directly as a



The envisaged cyclical 'ammonia economy', including direct end uses in the agricultural, transportation, energy storage, medical and construction sectors all made possible by electrochemical generation of green ammonia using renewable energy sources.

Reprinted from MacFarlane et al., doi.org/10.1016/j.joule.2020.04.004



Planetary nitrogen cycle shows how complex this system is and how little is known about it (33–213 Tg/year of ammonia is unaccounted for). BNF – biological nitrogen fixation.

Redrawn from Fowler et al., doi.org/10.1098/rstb.2013.0164

... CSIRO has already developed the catalysts to crack ammonia into nitrogen and hydrogen gas for use in the hydrogen economy.

fuel source (see image page 18) and this idea has stimulated intense research and development. Surprisingly, viewed on a cost per unit of useful energy in a variety of transportation applications, ammonia already competes quite well.

End-use modalities already demonstrated include vehicle and marine engines, particularly in hybrid fuel internal combustion engines. Ammonia for use in power generation is being demonstrated at small scale (e.g. as a replacement for diesel generation) and large scale (e.g. supplementary fuel in gas- and coal-fired power plants in Japan). Interest is high in using ammonia directly in gas turbines for power generation. This development has also led to ammonia being considered as a jet fuel. A study on this topic concluded that ammonia would be similar to traditional Jet A-1 in terms of performance, while decreasing NO_x emissions (doi.org/10.3390/en11020392).

Lastly, ammonia can be used directly in solid oxide fuel cells and direct ammonia fuel cells to produce electricity. The former operates at high temperatures to ensure conversion efficiency and is forecast to be used in applications with high energy demand (e.g. the marine sector).

Although catalytic converters already used with traditional fuels are commonly transferrable to this sector,

it is important to note that NO_x emissions from ammonia combustion do need to be carefully monitored and treated. This topic is already clearly in focus in most development studies.

Increased ammonia use and the Earth's nitrogen cycle

To correct the present imbalance in the Earth's carbon cycle generated by excess CO_2 emissions, only to create a similarly damaging imbalance in the nitrogen cycle, would be counterproductive. Through ammonia production for the agricultural sector via the Haber–Bosch process, anthropogenic nitrogen fixation already accounts for double that of natural processes. Although planned as a circular economy where NH_3 releases energy when cracked back into N_2 and H_2O , extreme caution is required, as even small adventitious losses of reactive nitrogen/ NO_x side products will accumulate substantially due to the scale increase. Compared with the planetary carbon cycle, less is understood about the nitrogen equivalent. Nitrogen is fixed at a rate of 413 Tg/year of which 50% is from anthropogenic sources; 200–380 Tg/year of the fixed nitrogen is accounted for and returns to the unreactive form N_2 , leaving 33–213 Tg/year unaccounted for. Knowledge gaps about the load processed in the deep ocean, where N_2O , a powerful greenhouse gas,

accumulates with a half-life of 100 years, require thorough scientific study. Further, limited information is available regarding denitrification processes in the atmosphere.

Ammonia has ideal chemical properties to become a significant, easily transportable fuel for the supply of energy globally. Producing ammonia without carbon emissions is possible and the roadmap that this article summarises describes the pathway towards this in terms of three generations, the third of which is the electrochemical approach. Although faced with challenges, this latter method breaks the reliance on traditional, inflexible Haber–Bosch technologies. Ammonia can be viewed as a hydrogen carrier; however, many direct-use modalities are also at various stages of development and conventional fuels can be replaced by ammonia with similar or improved safety. The future of ammonia as an ideal store of renewable energy and fossil fuel replacement is rapidly becoming an exciting reality and as a result has the potential to become a massive renewable energy export industry for Australia.

Dr Jacinta M. Bakker is a research fellow in the School of Chemistry and **Professor Douglas R. MacFarlane** is an Australian Laureate Fellow and Sir John Monash Distinguished Professor at Monash University.



High & dry

iStockphoto/witte-art_de

Priorities for our water insecurity

BY **DAVE SAMMUT** AND **CHANTELLE CRAIG**

For the driest inhabited continent on the planet, water security is a pressing concern.

The writing is on the wall, in letters several metres high: Australia is terribly vulnerable.

Safe, secure supplies of water are a critical part of this problem. Non-profit NGO The Nature Conservancy put the water security issue succinctly in their 2019 report *Wellspring: source water resilience and climate adaptation*: 'The climate crisis is a water crisis. Nine-in-ten natural disasters are water-related ... too much water and increasing extremes go hand in hand with far too little water; periods of drought align with flows of refugees and conflicts.'

As noted by the Bureau of Meteorology in its *Water in Australia 2018–19* report: 'The health of our communities, industries and natural environments is dependent on secure water supplies'. Water security can therefore be predicted to be a major issue for Australia in years to come, particularly as the effects of climate change continue to worsen.

Australia's water security is part of a broader landscape of vulnerability. Our lack of local production and capacity, our reliance on imported goods and on exports that are either unimproved (mining and other primary production) or politically

vulnerable (education and tourism), or both, leaves us at risk to any interruption in global trade.

One of the many people who have been trying to warn us is former Air Force deputy chief John Blackburn: 'Almost all our trade – 98 per cent of our trade, imports and exports – depends upon foreign-owned shipping systems, so we are actually in a pretty fragile position', he said as part of an ABC news article in April ([ab.co/334aKW6](https://www.abc.co/334aKW6)).

Having left the Department of Defence after 30 years, Cheryl Durrant (formerly Director of Preparedness) also spoke to the ABC. She's drawing

attention to a joint effort between the Department of Defence and Engineers Australia, the Industry Responses in a Collapse of Global Governance workshop in February 2019.

Describing a modelling exercise conducted at the workshop, she said: 'We saw three main possibilities of [a global crisis] happening: the increasing and escalating effects of climate change and natural disasters; a global power conflict, probably between America and China; and finally a pandemic – one with a much greater death rate than what we're seeing with the COVID crisis'.

These outcomes are alarming. With Australia almost entirely dependent on imports for most specialist medicines, shortages were predicted immediately following a major interruption of global supply chains. Public and industrial hoarding were similarly predicted to occur in the first days of a crisis.

Critically, water treatment systems – and therefore our supply of clean, safe drinking water – were predicted to begin to fail after just one week, such is our reliance on imported chemicals in the water treatment sector. Within two weeks, mass lay-offs, cessation of export mining operations, and the first interruptions to the supply of goods and services would happen. Within a month, with shortages of liquid fuel, food supplies would also begin to run

out. And you don't even want to know what was predicted within three months.

With the COVID-19 crisis, we've seen the first hint that many of these predictions could become realities. Being a less severe pandemic than posited for the exercise, the disruptions we've experienced are less complete or disastrous than those modelled by Engineers Australia, but the effects have still been severe. At the time of writing, we are enduring the pandemic's 'second wave', with no real sense of how long our society and economy will take to recover.

The crises modelled by Engineers Australia and the Department of Defence can be separated into two groups – those, such as war and pandemic, that would likely happen suddenly, but (hopefully) avoidably; and those, such as climate change, which will take longer to manifest, but (unless some global epiphany should occur) are now pretty much inevitable.

Our primary source of water is rainfall. However, according to the Bureau of Meteorology: 'High year-to-year variability in rainfall and increasing demand for water resources presents unique challenges for water management in Australia'. And Australia's total annual rainfall in 2018–19 was the lowest in almost 50 years.

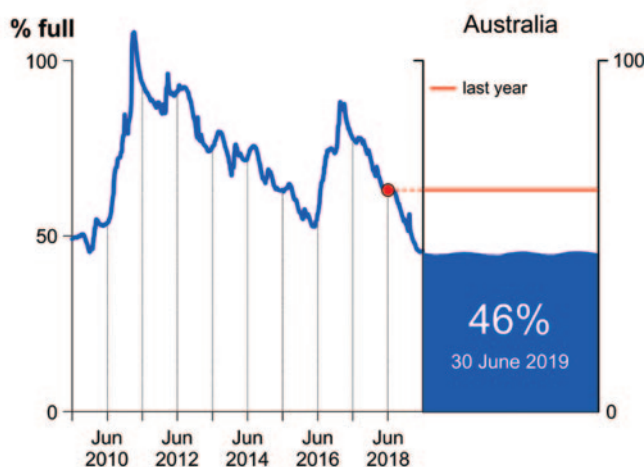
To preserve our rainfall, we need storage. Australia has more than 500 major and thousands of small storages, plus more than two million farm dams. But with drought conditions, accessible storage volume decreased during 2018–19 from 63% to just 46%, the lowest figure in a decade.

Major storage can also be used for electricity generation, but storage has environmental drawbacks, and the release of 'natural' flows is vital for many river ecosystems.

When storage falls short, Australia turns to desalination by reverse osmosis. Perth was first in Australia with its Kwinana plant. Sydney has Kurnell, and new plants have been built in South Gippsland (Victoria), Adelaide and the Gold Coast, in addition to more than 260 small facilities nationally. The five major urban centres in Australia have a total seawater desalination capacity of 534 GL/year.

But this isn't a 'flick the switch' arrangement when drought hits. After several years on care and maintenance, Kurnell's restart was initiated at the end of January 2019 (when dam levels hit 60%), with an eight-month restart period – delivering first water in March 2019 and reaching operational capacity by the end of September.

... with drought conditions, accessible storage volume decreased during 2018–19 from 63% to just 46%, the lowest figure in a decade.



Time series of storage volume as a percentage of capacity for combined urban and rural storages. © Commonwealth of Australia 2020, Bureau of Meteorology



CSIRO claims it is so effective that Sydney Harbour water passed through in ready-to-drink form, and that it increased antifouling membrane life significantly.

The GraphAir film developed by CSIRO. CSIRO

The traditional process of desalination is pretty straightforward. Filtered seawater is forced under high pressure through a semipermeable membrane. The smaller water molecules pass through, while the larger salt 'molecules' are trapped. The source side ends up as highly saline brine, which has waste problems, even with ocean disposal. It can affect marine life through altered local salinity, higher temperature and severely reduced levels of dissolved oxygen.

Care needs to be taken to minimise the number of fish sucked in. The Kurnell plant keeps intake linear flow rate at <0.1 m/s, with an interesting video showing fish swimming comfortably around those flows (www.sydneydesal.com.au/how-we-do-it/infrastructure).

The fresh water output from desalination must be further treated – vital minerals are reintroduced, the water is chlorinated for disinfection, and fluorinated for dental hygiene. This means that our desalination capacity is equally vulnerable to the interruption of supply in vital chemicals as our drinking water storage. In the wake of COVID, it has been reported that many water treatment plants have expanded their stockpiles of treatment chemicals, but generally this has been from two to four weeks' supply.

As newer plants, desalination plants are also more vulnerable to cyber attack. Ironically, our main infrastructure is comparatively safe from cyber attack owing to its ageing status and lack of investment in modernisation.

This might be an opportunity for new technology enhancements to reverse osmosis. Various researchers have been developing alternatives based on the use of graphene. CSIRO's GraphAir process creates a film with microscopic nano-channels, using renewable soybean oil, claimed as a faster, cheaper and more environmentally friendly production process for graphene. CSIRO claims it is so effective that Sydney Harbour water passed through in ready-to-drink form, and that it increased antifouling membrane life significantly.

And this coating of existing membranes is an idea being pursued around the world, with recent papers published from the University of Manchester and Wuhan University, both on similar principles. Graphene is very strong. It can form regular sheets just one atom thick, with nanometre-sized pores. It is hard to achieve mechanical strength in isolation, because any defects in the lattice weaken the structure, but when coated onto an existing membrane it combines the properties for both

performance and endurance.

The other major alternative to produce potable water in Australia is water recycling, primarily through the treatment of sewage flows. This represents about 7% of the total water sourced in major urban centres, and the Bureau of Meteorology predicts that usage will grow as dual-pipe systems are installed in metropolitan growth corridors. However, there has been considerable consumer resistance to the use of this water for drinking purposes, so the 124 GL of recycled water produced in 2018–19 was used for irrigation, industrial and non-potable domestic uses, and groundwater recharge. This helps bolster supply, but it fails to solve the fundamental vulnerabilities in our infrastructure.

Overall, if there is any positive that might come from the current COVID crisis, it might be hoped that our government, our industry and our society will be forced to sit up and take notice about just how fragile our systems are. Maybe, just maybe, we'll find the will to re-focus on our strategic needs and the major shortfalls in our capacity.

Dave Sammut FRACI CChem and **Chantelle Craig** are the principals of DCS Technical, a boutique scientific consultancy providing services to the Australian and international minerals, waste recycling and general scientific industries.

Drinking water under threat from bushfire

Rainfall after fire brings immediate relief but the environmental effects can sometimes be as significant as the fire itself.

Edith Cowan University (ECU) environmental experts Professor Pierre Horwitz and Dr Dave Blake are investigating the long-term impacts of water supply contamination after fire has swept through a region (doi.org/10.1071/WF18123).

Over the next four years in collaboration with the Water Corporation, the ECU researchers will lead a comprehensive investigation of forested water catchments in the Perth Hills from Mundaring Weir to Collie.

Blake said that water quality is not at the forefront of people's minds during the management of a fire, but this could result in problems with community's water supply for years.

'After vegetation cover is burned, and the soil is scorched, what's left is the concentrated and chemically transformed ash, exposed and vulnerable to wind and water erosion. Heavy rainfall will wash this ash, topsoil and incompletely burned vegetation into streams and water reservoirs', he said.

'All of this eroded matter is accompanied by dissolved organic compounds, carcinogens and heavy metals from the soil that are exposed and concentrated after a fire.

'Water treatment plants aren't set up to deal with this sort of contamination and can suspend water supply if faced with this.'

The ECU team completed an initial study in the Yarloop region in South West Western Australia after the devastating bushfire (also known as the Waroona blaze) destroyed more than 69 000 hectares of land in 2016.

Horwitz said water was one of the big concerns of the Yarloop community, a small town about 120 kilometres south of Perth, after the megafire.

'After the danger had passed, Yarloop residents were looking for immediate guidance on how to protect their water assets from the effects of the fire. So, having a better understanding of the long-term consequences for water would be a powerful tool to help to guide fire management protocol', he said.

Investigations in Yarloop helped researchers map erosion



In 2016, the rapidly moving Waroona blaze destroyed more than 150 homes and several other structures in and around Yarloop, Western Australia. NASA

hotspots and variable fire risk to determine potential contamination risks around water catchments.

'We found that in this region erosion was particularly harsh on steep terrain where the fire had been very severe', Blake said.

'Now we want to expand our work to a wider region, and consider land after fires of different burn intensities, like prescribed burns and wildfires, and wherever possible, collect pre-fire and fire history information as well.'

Horwitz said the research would lead to tools for environmental managers to apply in their areas to prevent post-fire erosion and subsequent water contamination.

'By factoring in the land topography, fire severity and rain intensity we can identify how long it takes burnt material to make its way into reservoirs used for water supply, then perhaps we can prevent the contamination altogether', he said.

'Understanding why some areas are particularly vulnerable will tell us where to go, and when and how, to stop particular sources of contamination from soil erosion after a fire.'

Edith Cowan University



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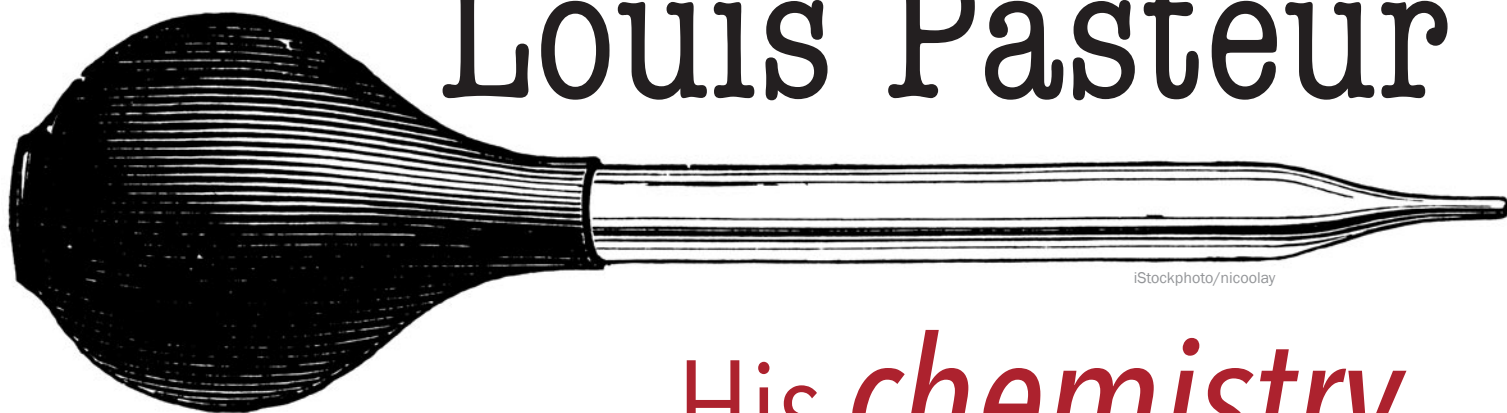
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Louis Pasteur



iStockphoto/nicoalay

His *chemistry* and *microbiology*

After making landmark discoveries in optical isomerism, tireless chemist Louis Pasteur progressed to work that would mark him as the father of microbiology and virology.

BY **ALF LARCHER**

Wik/Crisco



Photo portrait of Louis Pasteur, by Paul Nadar

While life is being overrun by tiny, spiked packets of biochemicals that are causing COVID-19, I've been watching in amazement the microbiologists, virologists, epidemiologists and infectious disease researchers explaining the complex biochemistry of this virus. To appreciate how this science reached such an advanced level, a look at the person who laid its foundation – Louis Pasteur – is a great place to start.

The Pasteur family origins were in various small villages in the Jura mountains, which straddle the present-day French–Swiss border. The Pasteurs were agricultural workers dependent on local priories, one family of which in the 1600s moved to the fertile plains below, to the town of Dôle where Louis Pasteur was born in 1822.

Louis' family moved to nearby Arbois in 1827, and it is here that Louis grew up, with his parents teaching their children the values of family loyalty, respect for hard work and financial security. At primary school, Louis readily led reading groups, as was fashionable at the time, although he only achieved moderate grades. His great love was pastel drawing and painting, and he completed a sizeable portfolio of works, using a wide variety of artistic techniques. It has been commented that Louis' paintings show the intensity and attention to detail that would serve him well in his scientific career.

During Louis' youth, influential educators and philosophers frequented the Pasteur family home and they saw something in the young man's determination and demeanour.

They encouraged him to apply for admission to the École Normale Supérieure in Paris, being originally established during the French Revolution as a training school for professors to teach the new ideas of the Enlightenment. Louis, at the age of 20, completed the entrance examinations for the École and was admitted, ranked 16th. Displaying his urge for perfection, Louis was not content with his rank and refused the École's offer. He waited another year, during which he further prepared for the entrance exams and, in 1843, his second attempt resulted in a higher ranking of fifth. He was happy to accept this and entered the École. This determination for perfection was another hallmark that Louis would bring to his scientific work.

Tartrates and optical activity

For his doctorate, Louis chose to study crystallography, an area of great interest at the time, with a number of unusual optical phenomena being observed in mineral crystals. But Louis was interested in a material a bit closer to his heart – the organic compound tartaric acid – a by-product of wine fermentation. This was found in thick, crusty deposits in wine barrels, familiar to him from the vineyards and wineries of his Jura plains boyhood. He had read extensively about the compound, as it had been known for some time that it existed in two forms: a large crystal form called tartaric acid and, occasionally found with it as a smaller needle form, paratartaric acid (now called DL-racemic acid – from the Latin *racemus* meaning 'grape'). What had puzzled chemists of the time was that, despite the two forms being chemically identical, a solution of the tartaric acid salt (i.e. the tartrate) rotated a plane of polarised light, while an equivalent solution of the paratartaric acid salt (paratartrate) was inactive.

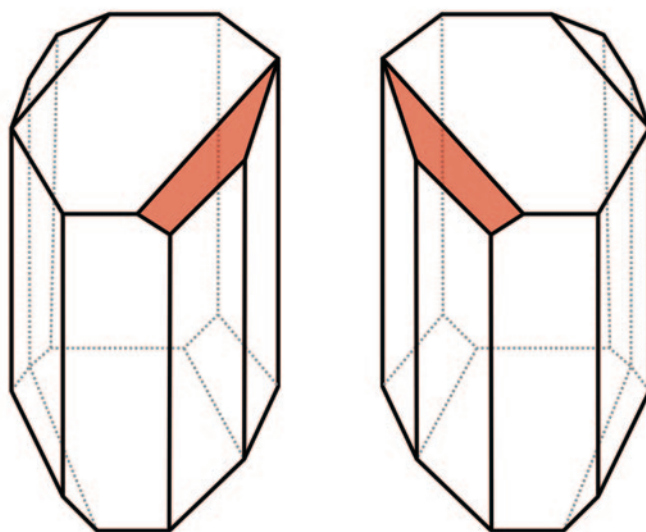
Louis' approach was to look at the crystals of the acids under a microscope. This was not a new

approach, but Louis saw what others had missed: the tartrate salts were hemihedral in form, having little faces on one half of the edges. Louis' keen artistic sketching eye picked up that the crystals of paratartrate salts were of the same shape but fundamentally different, being mirror images of themselves. The tartrate salt crystals, however, were all of one mirror image form or handedness. Louis then displayed his experimental brilliance by separating the two types of crystals in the optically inactive paratartrate salt, using tweezers under his microscope, and then making them up in separate solutions. As he expected, one solution rotated the plane of polarised light to the right, the other to the left. He had prepared solutions of tartrate salt and its optical isomers (enantiomers). Mixing the solutions once again resulted in an optically inactive mixture.

The reasons that some molecules have the property of chirality, forming optical isomers that rotate polarised light differently, would not be understood until much later, but Louis' discovery hastened the search for this understanding. Louis was also fortunate that he was studying mixtures of optical isomers that display the rare property of conglomerate crystallisation, forming mirror image crystals reflecting their parent compound's structure.

Unique experiments with fungus

With this remarkable discovery, Louis' reputation began its crescendo and he was able to secure a position as Professor of Chemistry at the University of Strasbourg in 1848. There he met Marie Laurent, a daughter of one of the university officials and two weeks later, being quite smitten by



Pasteur separated the left and right crystal shapes from each other to form two piles of crystals: in solution, one form rotated light to the left, the other to the right, while an equal mixture of the two forms cancelled each other's effect, and did not rotate the polarised light. Wiki/Brighterorange

her, wrote a letter to Marie's father asking for her hand in marriage. Marie agreed and they were married in 1849 with Marie becoming a constant companion and assistant to Louis, always showing interest in his work and encouraging him. Later in life she wrote to their five children, 'Your father is absorbed in his thoughts, talks little, sleeps little, rises at dawn, and in one word continues the life I began with him this day thirty-five years ago'.

At Strasbourg, the thrust of research work was still tartrate salts and, after pursuing some dead ends, he devised and completed another one of his decisive, brilliant experiments. He had observed, as others had in the university, that a certain fungus would grow in calcium tartrate solutions in warmer weather, spoiling them, which meant they had to be disposed of and replaced with fresh solutions. Louis wondered how the fungus would metabolise the mixture of optical isomers he'd observed previously; would it metabolise both equally? To address this, Louis grew the fungus in an optically inactive paratartrate solution (a mixture of both optically active isomers) and took progressive samples of the medium during the

fungus' growth, measuring its optical rotation. To his great excitement, he found the solution became progressively more optically active, rotating polarised light to the left. He produced crystals from the solutions and once again, with his tweezers under a microscope and his sharp eye, separated the two mirror image crystals and measured their relative amounts. He confirmed that the fungus was preferentially removing the right light-rotating isomer from solution. It was already known that plant-derived compounds were optically active, but the same laboratory-synthesised compounds were not. Louis' observations advanced the understanding of this phenomena markedly. He made much of this discovery, perhaps not fully appreciated by his contemporaries, claiming that it was key to understanding the origin of life. The significance of the discovery is increasing as chirality and stereochemistry are being used to search for life in extreme and astronomical environments. It appears to be unique to Louis, with no other researchers performing similar experiments leading to this significant finding.

Ferments, flasks and filters

Louis' research in Strasbourg had attracted more fame and monetary prizes, the latter spent mainly on laboratory equipment. Despite this, his laboratory facilities were still extremely limited so in 1854, at the age of 32, he accepted an appointment to the chair of chemistry and the dean of sciences at the newly reorganised University of Lille in the north of France.

At Lille, Louis became more involved in wine production problems, probably from his initial contacts he had made chasing various tartrate samples. Some of his 'pure science' colleagues did not approve of this work, with Louis' riposte being 'There are not two different kinds of science;

there is science and there are the applications of science'. The issue du jour among the local vignerons was inexplicable wine spoilage during production. The biochemical process of what we now call fermentation was not understood at the time. The current theory was spontaneous generation – the observed transformations thought to be the result of the materials in the medium somehow rearranging themselves to form new products. Louis once again decided to tackle the problem by looking at it under his microscope, which he did while holidaying at his country home at Arbois (where he had a fully equipped laboratory). There, he collected many

... Louis performed a set of brilliant experiments using a specially designed piece of glassware – the swan-necked flask.

grape juice samples at various stages of fermentation and made his characteristically detailed observations. In unspoiled samples, he saw 'particles' that others had already noted, but once again his keen eye observed more than others: small 'buds' seemed to form on these particles, with these buds eventually separating, growing and repeating the budding process. His mind started to tick – he had also observed that the grape juices were optically active, isolating an optically active component amyl alcohol. Were these particles the yeast? Was it a living organism, like his fungus, preferring one optical form and responsible for the conversion of sugar to alcohol? He furthermore observed that the 'particles' in spoiled wines were smaller and of different shape. Were these competing yeast-

like organisms that had the disrupted the normal yeasts?

And what of the souring of milk where sugar is converted to the unpleasant-tasting lactic acid – was this also due to these small living particles or 'ferments'? Louis discovered that these fermentation processes could be slowed down or sped up by adding various agents that changed such properties as acidity and temperature. He also developed agents, which he called 'antiseptics', that would kill these living particles. These techniques were important predecessors to his later virus work.

In 1857, Louis returned to the school he had graduated from in Paris, the École Normale Supérieure, as its assistant director, once again hoping that his rise through the administrative ranks would give him access to bigger laboratory facilities. He continued his fermentation studies, where he tried to determine whether these processes were the result of living organisms. To achieve this, Louis performed a set of characteristically brilliant experiments using a specially designed piece of glassware – the swan-necked flask. He began to make the flask by placing some fermentable fluid into a boiling flask after which he drew the flask's neck upwards into a thin tube, then further caressed the tube into an S-bend at right angles to the flask's neck. He then boiled the contents of the flask, the generated steam flushing the ambient air from it. Cooling resulted in the external air being drawn back into the flask through the contorted S-bend. Various particles in the air containing yeast and other microorganisms were trapped during their journey in the lower S of the bend, resulting in the flask's liquid remaining clear and unaltered. Tipping the flask so the liquid contacted the trapped material in the S-bend and then re-inverting resulted, after a short while, in fermentation. Some of these flasks are on display at the Pasteur Institute in Paris, with their contents still clear and unaltered more than

100 years after their preparation. A remnant of the swan-necked flask is the pasteur pipette, present in many of today's laboratories.

Louis did not rest; he followed up these experiments by filtering air through gun cotton and microscopically observing the entrained microorganisms. He then grew and 'cultured' his yeasts in novel synthetic mixtures of nutrients and noticed that some microorganisms did not require oxygen but survived in oxygen-free, anaerobic environments. He had founded the science of microbiology.

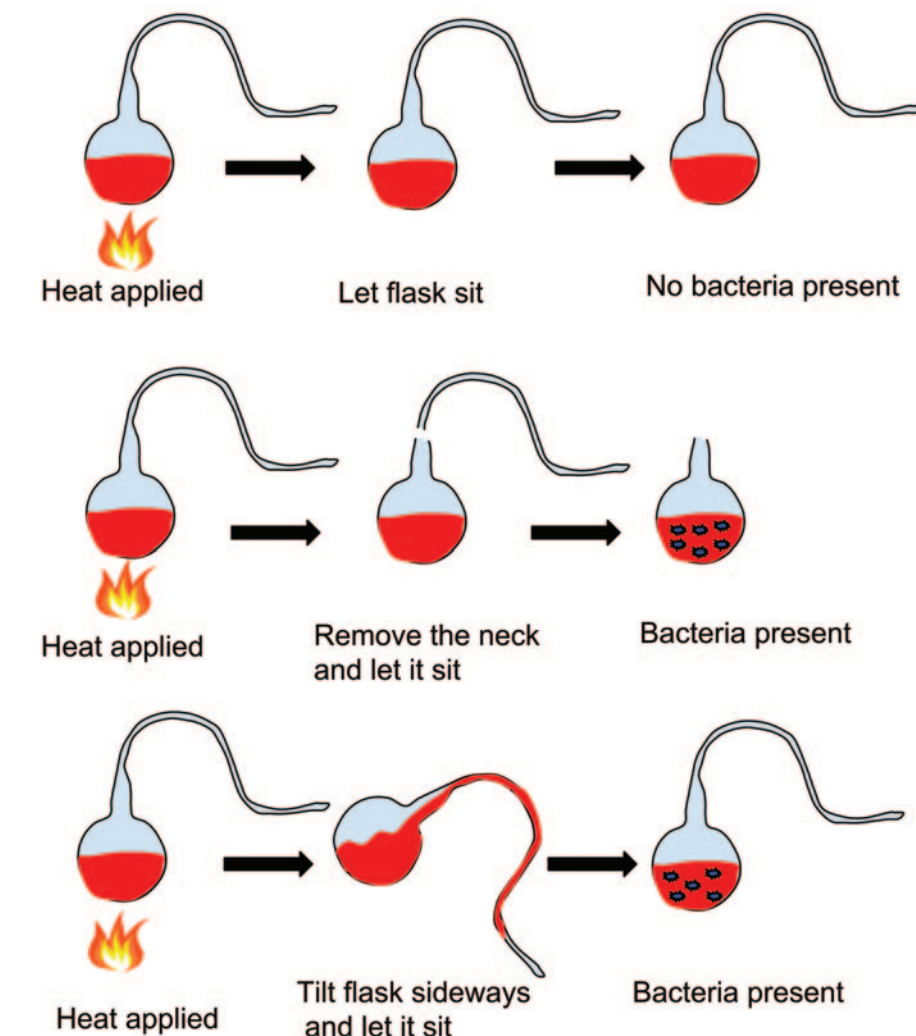
Setting his sights on French agriculture, Pasteur introduced various hygiene and heating treatments to promote the desired microorganisms, and reduced the spoilage of wine, beer and milk. The heat treatment of raw milk to increase its shelf life still bears his name – pasteurisation.

During these studies, the sanctity of Louis' laboratory, which he always insisted on, was somewhat challenged: the tasting of beer from new production techniques, punctuating the usual silence with the clinking of glasses and gentle laughter. On one occasion, when Louis was enthusiastically describing the technical details about beer production and microbiology to one of his assistants, the assistant was heard to say 'Mr Pasteur, you do realise the purpose of making beer is to drink it!'

Louis had also linked microorganisms with putrefaction and now began to promote the concept of them also causing human disease. Based on Louis' work, Scottish surgeon Joseph Lister put in place meticulous precautions to prevent microorganism contamination during his surgical procedures, thus reducing the surgical mortality rate dramatically.

Silkworms, cholera and anthrax

Following Louis' swan-necked flask work, fate was to give him a chance to study disease more closely – not in humans, but in silkworms. Learning that a mysterious disease had afflicted



Louis Pasteur's pasteurisation experiment illustrated that the spoilage of liquid was caused by particles in the air rather than the air itself. Wiki/Kgerow

France's silkworms, causing major economic hardship, he decided to investigate, completing the work from 1865 to 1870 in a makeshift laboratory in a house in Alés, southern France. Louis worked assiduously, carefully studying every step of the silkworm's life cycle with his trusty microscope, discovering that the silkworms were not spinning their valuable silken cocoons because of two diseases – pébrine and flacherie (now known to be caused by a protozoan parasite and a virus respectively). From his observations, he was also able to determine which silkworms were infected with the diseases and trained silkworm farmers to remove infected silkworms from their stock, gradually purging the disease. This was the first success of laboratory science in control of infectious disease.

Louis moved up a gear to study a

then common disease causing the death of farmed animals – anthrax. Louis' study of this disease concentrated on the developing immunity in uninfected animals. He had also been studying chicken cholera, caused by the bacterium *Pasteurella*, and had noticed that cultures of chicken cholera left on the Arbois laboratory shelf over summer no longer killed chickens. Furthermore, when these chickens were injected with the normal cholera bacteria, they did not die. Preparing this attenuated culture at elevated temperature, Louis found it could routinely prevent cholera in chickens that had been injected with it. Using similar attenuation techniques, he attenuated the sheep anthrax bacteria, which was decimating flocks throughout France, and, in a spectacular field trial in 1882, successfully demonstrated the viability of his vaccine.

The ultimate challenge – human rabies

Louis applied the techniques he had developed with chicken cholera and anthrax to rabies. The decision to study rabies is seen by historians as odd because the disease caused a comparatively low number of deaths in France at the time. However, when he was a boy, Louis had witnessed a rabid wolf terrorising the inhabitants of Arbois, biting people and animals alike in a frenzied attack. He also witnessed attempts to save the bitten casualties by cauterising the wounds with red-hot blacksmith irons, and the suffering of those who contracted the disease.

Rabies is caused by a virus and is usually transmitted in people through contact with saliva with broken skin, typically via a bite from a rabid mammal. The virus travels through the central nervous system and reaches the brain, after which symptoms appear. This incubation period is typically several weeks but is less if the bite is closer to the brain. Severe neurological symptoms develop and, even to this day, if symptoms progress to this stage the disease usually results in death.

Louis began his work by looking at rabies-infected material under a microscope and could find no causative agent. He carried on regardless, suspecting that it was a smaller microorganism than bacteria, and developed entirely new methods to handle, culture and attenuate it. Louis' trusty laboratory assistant of many years, Emile Roux, devised how to study the length of survival of the virus in the spinal cord of rabbits, using a specially designed bottle with two openings. Louis adapted Emile's techniques and suspended rabbit spinal cords containing the virus in the bottles with some desiccant, producing a non-virulent form of the virus. Courses of emulsions made from these attenuated spinal cords were inoculated into dogs and found to provide immunity towards the disease.

... when he was a boy, Louis had witnessed a rabid wolf terrorising the inhabitants of Arbois, biting people and animals alike in a frenzied attack.

The next step was possible human trials, which Louis did not look forward to, knowing full well the horrors that an unsuccessful trial could bring in terms of possibly causing untreatable rabies in the patient. Opposition also came from abroad, from the eminent microbiologist Robert Koch, and from within, with Emile Roux stating that the potential vaccine was far too dangerous and that he would not have anything to do with any human trial. But Louis' hand, and his heart, was forced by fate, when in 1885 two doctors brought to him a young boy, Joseph Meister, who had been viciously bitten by a rabid dog. The two doctors knew of Louis' work and were convinced that since rabies had a long incubation time, a course of Louis' vaccine during this would cause immunity in the patient. Louis was not a trained medical doctor and thus could not administer the vaccine; the two doctors said that they would take full responsibility for the boy's fate. Louis must have known that the boy's life, his personal reputation and any further chance of using the vaccine was at stake. He conceded, and after 12 successive inoculations of increasingly stronger attenuated virus, the young boy did not develop rabies symptoms and was allowed to go home. A second success followed, involving a young shepherd boy, and after 15 months 2490 people had received the vaccine.

The indefatigable Louis completed much more research, but the development of the rabies vaccine was his last major achievement. In his lifetime, he received many awards and adulations, and he lobbied the government to set up a purpose-built research institute, which to this day bears his name. His application of theoretical work to solve major agricultural and societal health problems is a showcase for the power of scientific research. Louis had a stroke in 1894, from which he did not recover. He died on 28 September 1895, near Paris. He was given a state funeral and his remains are interred in a vault of the Pasteur Institute in Paris.

Alf Larcher FRACI CChem is a petroleum, environmental and industrial chemist with an occasional urge to write science articles. The author has used mainstream references (full list available on request) from recognised sources.

Pasteur and Australia's rabbit plague prize

Louis' chicken cholera work had an Australian connection: Louis had read about the worsening rabbit plague in Australia and the 1887 New South Wales government prize of £25 000 (\$10 million in today's terms) for any method that would exterminate the rabbits. Louis' team had used chicken-cholera-laden food to kill rabbits in a small-scale trial in France, and Louis thus dispatched his laboratory assistant Adrien Loir to Australia with vials of chicken cholera in his luggage. The NSW government set Adrien up on Rodd Island, on a quiet bend of Sydney's Parramatta River. There, it was once again found that the chicken cholera killed rabbits that had ingested food laden with it, but it did not transmit to other rabbits. They did not receive the prize, but while mulling over the results, the team heard that a mysterious disease was killing sheep and cattle in the area. Determining it to be anthrax, they promptly set up facilities to manufacture the vaccine, which over the next four years they sold to graziers, making a healthy profit.



New Fellow

Matt Piggott obtained his BSc with majors in organic chemistry and biochemistry/molecular biology from the University of Western Australia. His Honours project, supervised by Rob Trengove and the late Emilio Ghisalberti, involved an investigation of the essential oil of Western Australian sandalwood, *Santalum spicatum*. In his PhD studies with Dieter Wege, Piggott achieved the total synthesis of several

isofuranonaphthoquinone (and related) natural products. He then took up a postdoctoral fellowship at the Australian National University, where he worked on antibiotic drug discovery with Martin Banwell and Chris Easton, in collaboration with GlaxoSmithKline. His second postdoc, with T. Ross Kelly at Boston College, involved research directed at the synthesis of a chemically powered, unidirectional molecular motor.

Piggott was appointed to an academic position at ANU in the Department of Chemistry in 2003, and in 2005 moved to the University of WA, to what is now the School of Molecular Sciences. He is a teaching and research academic, and was heavily involved in University of WA's offshore life-science degrees in Singapore 2007–2018.

Piggott's research interests are eclectic, but revolve around synthetic organic chemistry, enabled by talented honours and PhD students. Past and present projects include:

- total synthesis of biologically active natural products and designed compounds with interesting (beautiful and or potentially useful) molecular structures
- molecular electronics
- development of chemical probes with biological applications (chemical biology)
- medicinal chemistry directed at drug discovery for Parkinson's disease, trypanosomiasis (African sleeping sickness and Chagas disease), cancer and spinal cord injury.

One of Piggott's early independent research projects involved medicinal chemistry inspired by MDMA ('ecstasy'). As a result, he has been called on extensively to provide expert opinion and evidence in legal cases related to clandestine drug synthesis and possession.

Piggott has been a member of the RACI since 1995, with a brief stint as the Western Australian representative for the Organic Division, and since 2014 for the Division of Medicinal Chemistry and Chemical Biology. He was a member of the management committee of this magazine for several years, during which time he instigated and compiled the Research column. With Mick Sherburn and Scott Stewart, he co-chaired the 2018 RACI Organic Division national conference, Organic18, at the University of WA in Perth. Piggott received the Athel Beckwith Award, and the Biota Award for Medicinal Chemistry (now the Peter Andrews Award for Innovation).

Maurice Mulcahy

A man of learning and culture

Dr Maurice Francis Robinson Mulcahy was born on 13 February 1920 and died in Sydney on 30 January 2020, two weeks before his 100th birthday.

Maurice became a member of RACI in 1942 while at the University of Melbourne. He was elected a Fellow in 1953, his membership spanning a total of 78 years.

Maurice was a physical chemist whose DPhil (Oxon.) was awarded in 1948 subsequent to his research on the initiation and propagation of explosives in liquids. This research, which was begun at the University of Melbourne in the CSIR Lubricants and Bearings Laboratory during World War II, was conducted under the supervision of Professor Sir Cyril Hinshelwood at Oxford University. In the same year, he was awarded the Rennie Medal by RACI.

His was a distinguished career both in Australia and internationally. He was awarded the degree of DSc (Oxon.) in 1971 for his research in chemical kinetics, combustion and atmospheric chemistry. Throughout his career, he published numerous research papers, reviews and reports. His highly acclaimed book *Gas kinetics* was published in 1973.

He was the first Australian scientist to receive a Combustion Chemistry Award from the Royal Society of Chemistry. This award, which was given in 1983, was in recognition of his research into the chemistry of combustion generally and especially in relation to the combustion of coal particles, the formation of pollutants in flames and the reactions of atoms and free radicals in the atmosphere.

Maurice retired from professional life in 1983. At this time, he was Assistant Chief of CSIRO Division of Fossil Fuels in Sydney. Following his retirement, he accepted a number of international visiting professorships and remained an honorary research fellow with CSIRO for several years.

In 2003, he was awarded an Australian Centenary Medal in recognition of his many years of extensive research into the atmospheric chemistry of photochemical smog and urban brown haze. This research had a profound effect on the understanding and management of these issues both nationally and internationally.

Maurice was not only a distinguished and widely recognised research scientist, he was also a man of learning and culture. His love of reading and books is legendary and over his lifetime he created a library of many hundreds of books that reflected his wide range of intellectual and scholarly interests.

Dr Maurice Francis Robinson Mulcahy was a true gentleman in every sense of the word. His passing marks the end of an era in so many ways and he will be greatly missed by his family and friends. He will be remembered as an eminent scientist, a revered and learned friend, and a role model and mentor to all who knew him.

Helen Anderson

Graeme Paul

Community-minded industrial chemist

Graeme Paul (1 September 1943 – 11 June 2020) was passionate about how chemistry could help the community in many aspects, both in Australia and in Papua New Guinea. Graeme had the ability to identify a community need and see projects through to completion. This obituary was assisted by Graeme, who documented his experience as a full-time worker/part-time university student and subsequent career in the chemical industry. His story will resonate with older RACI members who as trainee and junior chemists moved between companies seeking experience while advancing their career. Searching for potential employers via the old-fashioned telephone book, young Graeme 'cold called' chemical manufacturers. This resulted in his first job at the Selleys Chemical Company, Marrickville, New South Wales. A variety of occupations and chemical specialties followed.

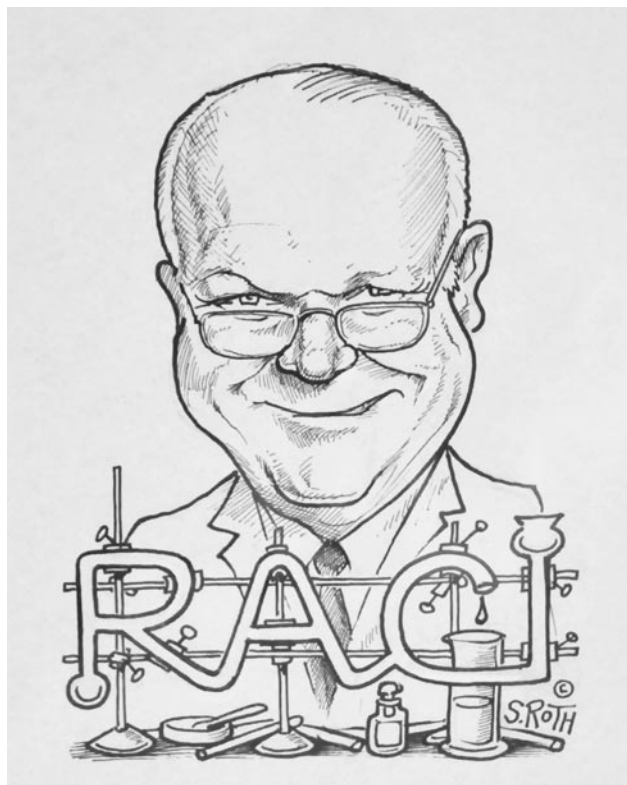
Selleys focused on the DIY market with putty, caulking compounds, adhesives and aerosols products, including RP7, to which Graeme made contributions. The captivatingly named House of Fonteyn supplied paints, perfumes, specialty chemicals and aerosol products, which required additional skill and responsibilities for Graeme. This experience resulted in a production manager position at Dermacos, a major aerosol product manufacturer. The offer of plant superintendent at the ICIANZ specialist catalyst company Catoleum was a career highlight, eventually dashed by the take-over by W.R. Grace. Not one to loiter, Graeme was employed as production manager at the bulk newspaper ink manufacturer F.T. Wimble Inks.

Graeme's contribution to smudge-free bulk newspaper ink technology resulted in him being awarded the 1992 Whiffen Medal (Neville Whiffen being an Australian pioneering chemical engineer) by the Institution of Chemical Engineers. Graeme was also awarded the 1997 RACI Industrial Chemistry Division R.K. Murphy Medal (R.K. Murphy being a founder of RACI).

In 1991, F.T. Wimble Inks' Ink Division and its affiliate Colorpak were acquired by SICPA, the Swiss-based international ink maker. Graeme was then employed as general manager with the privately owned Hardman Chemicals, which was also the target of company buy-out (three times unlucky). Next, Graeme was a consultant with legal expert witness exposure also working with the late Professor David Trimm and CSIRO on high temperature/pressure reactors for catalytic conversion of LPG into liquid petroleum fuel. In early 2000, Graeme was employed as the Technical and Manufacturing Manager for the specialty chemical company K.K. Kingston (largest manufacturer in Papua New Guinea) until he retired in 2008.

Graeme was educated at The Scots College, Sydney, University of Technology, Sydney, and University of New South Wales (School of Chemical Engineering & Industrial Chemistry) (BSc 1970).

Graeme was a committed and enthusiastic member of many associations, including RACI (FRACI 1991, National President



1995, Chairman of the Industrial Chemistry Division, Citation 2000); Institution of Chemical Engineers (ICHEME) (President, FICHEM 1989, CEng, Chemeca 1992 Secretary); Federation of Asian Chemical Societies (life member 1996); Australian Council of Professions (President); Rotary International (Paul Harris Fellow, President Frenchs Forest, NSW, and Huon Bay, Lae, PNG). Graeme, together with other committed Rotarians, arranged donations of books, school equipment, water and medical equipment and equipped Lae Fire Brigade with a fire engine, protective clothing and footwear –'no more barefoot firemen'. Graeme found time for involvement with the Institute of Petroleum, Geological Society of Australia, Manly Surf Club (lifesaver and volunteer beach inspector), State Emergency Services (Deputy Inner Division Controller), Rural Fire Services (1999–2020), Manly & UNSW Rugby Union (referee and first aider), Red Cross, and Masonic Lodge Dee Why (1974–2001).

Graeme was recognised in the Australia Day Awards Northern Beaches, Outstanding Community Service (March 2020). This award detailed Graeme's wide range of community activities, which included a bush tucker garden at Davidson Park. Graeme also received other awards from Autism Spectrum Australia, NSW Government 2001–2002 Bushfire Campaign and the National Parks and Wildlife Service (Certificate of Appreciation 2018).

In spite of his medical prognosis, Graeme fought on. Graeme will be sadly missed by his wife Marilyn and children Amanda, Carolyne and Douglas, and by his numerous friends from many walks of life.

Robert Ryan FRACI CChem, Catherine Ossolinski MRACI and Iain Schwilk

Kenneth Gillbanks ‘Ken’ Tinley

Industrial research chemist

Ken Tinley ASTC, FRACI CChem passed away on 13 June 2020 aged 92 years. Ken had a long career as a research chemist in the building products industry and was an active member of the RACI in the 1980s and 90s.

Ken was born in Brisbane on 13 March 1928 to Harold and Annie Tinley. He was the much younger brother of Hazel, who had her parents to herself for eight years. Ken spent his childhood in Greenslopes, attending Brisbane Grammar School. The family moved to Sydney at the beginning of World War II when Harold was appointed auditor to the Commonwealth Bank in its then capacity as central bank (precursor to the Reserve Bank). The family lived in Mosman and Ken went to Sydney Grammar. Ken always considered himself a Sydney citizen with a Queenslander's view of essential things such as the joy of drinking sarsaparilla and choosing not to swim in what he considered to be the cold waters of Sydney.

Ken liked to defy medical expectations. Doctors had told his parents that he would be unlikely to reach 20 as he had such a weak chest. With typical quiet determination, he set about proving them wrong. Ken loved bushwalking from an early age and spent a lot of his youth hiking and camping. He was a scout and rover with Mosman Sea Scouts and enjoyed a very active youth.

Ken graduated from Sydney Technical College with an associate diploma. After graduation, he established a paint production company with his friend Brian Cant, which kept him busy for a decade.

Ken joined Concrete Industries (Monier) Limited in the mid-1960s, serving in various technical roles and rising to the position of research manager. Ken's work at Monier was varied and encompassed all aspects of building products technology, including concrete, tiles, adhesives, fasteners, flashings and vents.

Like most industrial chemists, Ken didn't have much opportunity to publish because of commercial considerations, but his work resulted in a number of patent applications and granted patents. Ken was also responsible for sourcing and approving raw materials and his young family enjoyed accompanying him on trips to the bush to inspect deposits of sand and gravel.

Ken retired from Monier in the late 1980s and worked for several years as a consultant. Ken's detailed knowledge of the materials and processes used for manufacture of building products led to his services being in demand as an expert witness in court cases relating to 'sick building syndrome', a condition that arose in the 1970s where occupants of commercial buildings suffered a range of symptoms, including headaches, nausea and skin irritation.



He then returned to the mainstream workforce at CSIRO Material Sciences at North Ryde. Again, Ken's earlier experience and knowledge came into play with his work focusing on bonding of materials as well as exposure and durability evaluation. Ken retired from CSIRO at age 65.

Ken joined the RACI in 1969 and was a keen supporter of the NSW Industrial Chemistry Group and served as the NSW Branch representative on the Australian Council of Professions. He received the 1993 NSW President's Award for Services to the NSW Branch and was elected FRACI in 1996.

Ken followed a busy working life with an active retirement. Ken and his wife Helen travelled overseas and around Australia. Ken became president of the Central Coast Caravan Club and an executive of the Mount Colah Probus Club.

Ken is survived by his wife Helen and children Ian, Sue and Fran, Sharyn and Rob, Simonne, Mark, Megan and Nicole.

Philip Fleming FRACI CChem

WHY
TRUST
SCIENCE
?
NAOMI
ORESKEs

Why trust science?

Oreskes N., Princeton University Press, 2019, hardback, approx. 360 pp., ISBN 9780691179001, approx. \$30

Why trust science? is a complex, thought-provoking, scholarly, almost overwhelmingly ideas-and-concepts-rich tome. It is certainly not something to be embarked on lightly but is well worth tackling.

For me, it was enlightening to unveil aspects of science I had never really thought much about and broaden my perspectives on how science works, and why there are circumstances where trust in

science is justifiable, just as there are others where it is not.

Science and scientists don't always get it right, as author Naomi Oreskes explains. For example, it used to be argued, from the first law of thermodynamics no less, that women should not go to university because they only had so much energy to go around and wasting it on education would seriously impede other activities. Equally, eugenicists, dating from Francis Galton (1822–1911) to jaw-droppingly recent times, argued the best role for clever girls lay in propagating the species to enhance the overall herd IQ (which nobody understood overly much then or probably now!) What a load of scientific cobblers! There is plenty of fodder out there to feed, for instance, climate sceptics and their ilk: science has got it wrong before and no doubt will again.

Further, Oreskes cogently argues there is no single scientific method. We cannot fall back on the argument that we followed the mythical 'scientific method' so you can trust us. Rather, if science is to be trusted at all, it is because of its rigorous social vetting processes.

So, can we trust science? Oreskes gives qualified support to trusting science. In the past, learned societies admitted to their fellowship scientists judged by their peers to be pre-eminent: there were strict selection protocols so that in theory only people who were the 'real deal' were admitted and their trustworthiness was thus assured under the imprimatur of the society. More recently, the practice of science has developed a strong social element: it is embedded in its own social milieu, with its own robust formal and informal styles of communication, regulation and review. Scientists can rightfully claim a place at the table as the experts who are knowledgeable about how the physical universe works, worth heeding and probably right most of the time when they communicate on these matters.

Outside this domain, Oreskes argues scientists' opinions have no more weight than anybody else's. For example, as scientists we can quite properly advance the scientific rationale behind climate change (that is our role) but our arguments have no a priori legitimacy when we stray from our pulpit and wax about, for example, economic, political or sociological aspects

arising from climate change. Interesting? I'm reminded of the Billy Connolly skit where a comatose accident victim is lying on the roadway when the call goes out to the bystanders, asking for anyone who is a doctor. One such leaps into action, crying, 'Yes! Yes! I'm a doctor of aromatherapy'. Naturally, Billy commented at some length in terms you are unlikely to find in your primary school dictionary. It's all about horses for courses.

And what about science as a social activity? We go to conferences and meetings; we talk to each other; we email, Skype, Zoom, tweet etc. our distant colleagues; we belong to organisations such as RACI; we publish our work in socially mediated journals and so forth. There is a well-policed social orthodoxy guiding the questions to ask and those deemed unworthy. So, why then do we take this highly socialised, dare I say exciting, activity we call science and persistently and aggressively depersonalise and de-excite it right from the get-go, and wrap its utterances in the arcane third person past tense like some medieval Latin high mass? Are you surprised kids might find this a turn-off? I'm not.

... Oreskes cogently argues ... if science is to be trusted at all, it is because of its rigorous social vetting processes.

Author Naomi Oreskes was for 15 years Professor of History and Science Studies at the University of California, San Diego. For the past seven years she has been Professor of the History of Science as well as an Affiliated Professor of Earth and Planetary Science at Harvard University. The book is based on the 2016 Tanner Lecture series at Princeton University. It is a fiercely and cogently argued case that Oreskes presents. This occupies the first 160 pages or so and is followed by commentary chapters by Susan Lindee (University of Pennsylvania), Marc Lange, Ottmar Edenhofer and Martin Kowarsch (Mercator Research Institute), and Jon Krohn (Stanford University).

All in all, it is a very interesting book, which takes a fair bit of grappling with, but is well worth the journey.

There are two final thoughts I'd like to share. From the frontispiece: Trust but verify (Ronald Reagan). From a cartoon on page 159: A speaker at a Climate Summit pointing out on his displayed slide some of the advantages of climate mitigation (energy independence, preservation of rainforests, sustainability, green jobs, liveable cities, renewables, clean air and water, healthy children) is asked by an audience member, 'What if it's a big hoax and we create a better world for nothing?' Makes me want to cry.

R.J. Casey FRACI CChem



What stars are made of: the life of Cecilia Payne-Gaposchkin

Moore D., Harvard University Press, 2020, hardback, 320 pp., ISBN 9780674237377, approx. \$46

What stars are made of: the life of Cecelia Payne-Gaposchkin is the life story of Cecelia Payne (1900–1979). Cecilia was born, the eldest of three siblings, in 1900 at Wendover, a village about 60 kilometres north-west of London. Her father was a 55-year-old successful London barrister who, as was

the custom of the times, had married a younger wife (33 years old) and settled his family into a country manor house. Female children of Cecilia's class and generation were virtually predestined to follow in their mothers' footsteps and become good domestic managers, excellent in social skills, good procreators of the family line and, above all, amenable, docile and useful adjuncts to their husbands. In this late Victorian–early Edwardian era, working class girls were trained in domestic chores (if they were educated at all) and female offspring of the professional classes were essentially taught social airs and graces with a view to making a suitable marriage and certainly not with any notions of pursuing any sort of career. After all, surely pursuit of a career would be an indication of lack of success in the matrimonial stakes?

In any case, Cecilia was having none of it. From a very early age, she developed a strong interest in botany. At school, she bucked the trend, wanting to study mathematics and sciences. Her secondary school tried hard to accommodate her desires, using various stop-gap measures, but finally gave up and declined her final year re-enrolment. Fortunately, she was admitted for her final year to a strongly feminist girls' school (St Paul's) in London, where she was warmly encouraged in her intellectual pursuits and whence she successfully gained entrance to Cambridge University (Newnham College) in 1919 to study botany. At that time, women were an exotic species at Cambridge. Their entry into lecture theatres was frequently accompanied by foot-stamping, catcalls and unseemly remarks. They were required to sit at the front of the lecture theatres where they were generally ignored by their lecturers, and in practical classes frequently found themselves isolated down the back, well away from the main action. Of course they were expected to dress modestly, long drab skirts to the ground, under-layered with heavy petticoats and heavy stockings, and keep their hair short. For hockey, skirts a very few centimetres above the ground were permissible but woe betide any bare ankles. A couple of Cecilia's peers who went for a run, in their long skirts, but without stockings one warm Cambridge twilight found themselves carpeted by the college management! And, just to top it all off, women were not allowed to graduate from

the university: while they could fulfil the requirements for a degree, they were not able to graduate. That statute persisted until 1947. (For a time, women wanting to actually get a parchment went off to Trinity College Dublin, paid £10, and were automatically graduated. They were styled 'steamboat ladies'.)

Cecilia studied botany (which is very notable for its rigorous classification systems) but became disillusioned. She then switched to experimental physics (at the Cavendish Laboratory, where she was lectured to by Rutherford and learnt a lot about emission spectroscopy) and, almost as an aside, astronomy (in which she absolutely revelled and decided this was her life's calling). Were there jobs for female astronomers in the UK? Not on your Nellie! Advice was that she should look to the USA.

Cecilia did exactly that, going off to Harvard on a very meagre scholarship. In its basement, the Harvard observatory held a major collection (glass plates) of the emission spectra of stars. Cecilia's task was to try to make some sense of them. Prevailing wisdom was that stars were just like Earth, but hotter. Using her possibly unique background in classification, emission spectroscopy and astronomy, she reached the somewhat heretical conclusion that stars were almost exclusively hydrogen, along the way completing what is still considered one of the finest astronomy theses ever written. Subsequently, she became a Harvard employee and, after being unconscionably exploited in lowly paid short-term positions, eventually became the first female professor at Harvard to be appointed through regular faculty promotion, and a leading figure in world astronomy. She died in 1979.

So, this book is an interesting tale of a determined little girl who knew what she wanted and achieved her goals in spite of all the barriers and restrictions in her path. As I read it, I kept marvelling about how far human civilisation has advanced since those times. Then I think of a little girl in Pakistan, shot through the head for advocating education for girls (fortunately she survived, was awarded a Nobel Prize and has just graduated from university) and how, in my memory, female teachers in New South Wales went on strike in the 1970s for equal pay. Indeed, on marriage, they were ineligible for permanency in the teaching service. Women who worked in banks were also dismissed on marriage. Look around you! The lot of women in our society has certainly come a long way since Cecilia's day, but you do not have to look very hard before you realise that there is still a good way to go. If you are not inclined to believe me, read the foreword by Jocelyn Bell Burnell: it is blistering.

Let me conclude, as does the book, with Cecilia Payne's inspiring words.

Do not undertake a scientific career in quest of fame or money. There are easier and better ways to reach them. Undertake it only if nothing else will satisfy you; for nothing else is probably what you will receive. Your reward will be the widening of the horizon as you climb. And if you achieve that reward, you will ask no other.

R.J. Casey FRACI CChem

Patenting polymorphs: a complex process

In the high-stakes world of pharmaceutical development, companies pursue every opportunity to edge out competitors. Patenting polymorphs may provide that edge. Noticing a surprising, unexpected or unique physico-chemical characteristic of a crystalline form of a pharmaceutical may be the key.

A new pharmaceutical typically takes 10–15 years to progress from initial discovery, through to clinical trials and then to regulatory approval prior to market release. Less than 12% of new pharmaceuticals make it to market release, and the entire process may cost hundreds of millions of dollars.

The right to a temporary market monopoly under a Patent enables innovator companies to raise prices above production costs, recoup pharmaceutical R&D expenses and mitigate risk to investors. Otherwise, the unfettered competition would drive prices down to production costs and recouping costs would be impossible.

Polymorphs

Polymorphism refers to the ability of crystalline material to exist in more than one solid or crystalline form. It is believed that 50–80% of all pharmaceuticals exist in at least two polymorphic forms.

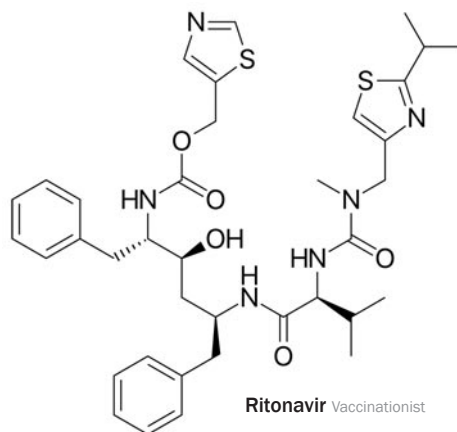
Most pharmaceuticals are used in a crystalline form. Polymorphic forms can potentially be characterised by techniques such as powder X-ray diffraction (PXRD), vibrational spectroscopy, including IR and Raman spectroscopy, and solid-state nuclear magnetic resonance spectroscopy (ssNMR).

To compensate for the drawbacks associated with one technique, multiple characterisation techniques are often used for polymorphic methods. PXRD is most useful for identifying polymorphic forms based on differences in unit cell dimensions, but it requires known or constant crystallinity for analysis. The application of pressure during sample preparation may induce solid-state phase changes when using IR. ssNMR suffers from insensitivity to particle size, but it is sensitive to minor conformational changes and provides extensive structural information in relation to the specific polymorph being studied. Vibrational spectroscopic methods are useful for obtaining information at the molecular level. Near-infrared spectroscopy (NIR) is fast and non-destructive and requires minimal sample preparation. However, NIR signals appear as abundant broad overlapping bands, which require the utilisation of chemometrics to extract useful information. Raman spectroscopy requires particle size and surface homogeneity control for obtaining accurate results and if visible lasers are used, fluorescence effects can pose a problem in colourless powders.

Pharmaceutical regulators, such as the United States FDA and the European Medicines Agency, require screening of polymorphs during new pharmaceutical development to uncover polymorphic forms and evidence as to whether the choice of

polymorph will affect the pharmaceutical efficacy or safety. This is because pharmaceutical polymorphs often differ in their physicochemical properties, such as solubility, dissolution rate, density, stability, hygroscopicity, wettability, hardness, optical and electrical properties. These differences can lead to different pharmaceutical properties that affect bioavailability, efficacy, metabolism and side effects. Formulation technology for the dosage form may have to be adapted accordingly.

The consequence of having different polymorphic properties was first noted in 1998 for Abbott Laboratories' antiretroviral HIV drug Ritonavir (Norvir™). The presence of multiple polymorphic forms in the Norvir™ product was not detected until changes in ambient temperature suddenly caused polymorphic transformation that reduced solubility and bioavailability of the drug. The drug was suddenly withdrawn from the market, which was a serious step for patients and for Abbott, until the source of the problem and a solution for it were found.



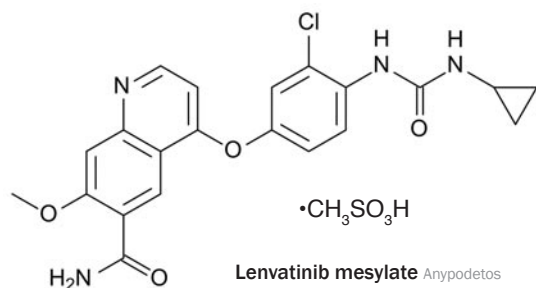
Patents

Patenting the structure of a new drug will ensure broad protection for that chemical entity, but will not necessarily ensure an adequate monopoly if any follow-on innovations are patented by others. Different polymorphs can require different methods of formulation or different dosage forms, each of which may be patentable, and a different scope of protection may be available.

Two key requirements for patentability are that an invention must be novel and it must involve an inventive step. That is, it cannot be obvious to the ordinary, un inventive person skilled in the art.

In Europe

The question of inventive step in Europe depends upon whether a Patent identifies a technical problem to be solved and whether that problem is routinely associated with polymorphs. Consider, for example, Esai R&D's Patent for Lenvatinib mesylate.



The problem to be solved was defined as lying in the provision of Lenvatinib in a form having an improved dissolution rate and bioavailability, low hygroscopicity and good stability. These properties are sometimes inversely related and, in this case, did not correlate with each other in the usual way. The skilled person, starting from Lenvatinib, would be aware of its physicochemical properties, and specifically that it is a weak base, by virtue of the presence of the quinoline moiety, with poor aqueous solubility. Moreover, the skilled person would be familiar with the standard literature. However, it was determined that the specific polymorphs of the mesylate salt claimed would not have been expected to deliver the desired combination of properties. Moreover, the skilled person would not have had a reasonable expectation that any arbitrary crystalline salt form of Lenvatinib would be equally suitable. Importantly, appropriate supporting data was provided in the Patent Specification. Accordingly, the Patent was found to possess an inventive step.

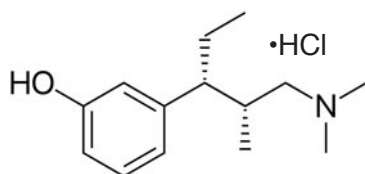
In the United States

Recently, the US Federal Circuit Court considered Grünenthal's polymorph Patent for Tapentadol hydrochloride (Nucynta™ ER) for treating severe pain. Polymorph Form A was held to be non-obvious and patentable in the light of an earlier Patent relating to polymorph Form B.

Importantly, there was no reasonable expectation of successfully producing Form A. The Court held that the ordinary, un inventive skilled person would have thought that synthesis of a stable Form A was unpredictable and was not a matter of mere routine experimentation.

In China

But in an interesting contrast in China, Grünenthal's Patent for Tapentadol hydrochloride was held invalid, the case turning on the issue of insufficient data appearing in the Patent Specification.



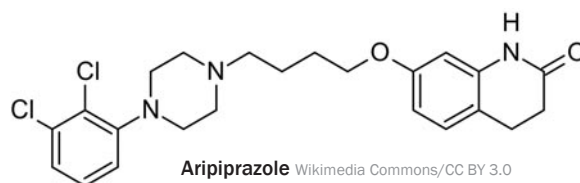
The Court opined that if a new crystalline form achieves unexpected technical effects compared with existing forms, it can be considered inventive. However, Grünenthal had insufficient data to support the assertion that one polymorph was more stable than the other. The Patent Claims relating to the method of crystallisation were also held to lack an inventive step. It appears that the Patent included general teaching of common crystallisation methods, as opposed to those that would lead to the new crystalline form having improved stability. The Patent Specification clearly would have benefited from the provision of data around the difficulties of arriving at the correct solvent system to crystallise a new polymorph having critical properties.

In Australia

The relevant question regarding obviousness in Australia is:

Would the notional research group at the relevant date in all the circumstances ... directly be led as a matter of course to try the [invention] in the expectation that it might well produce a useful [product/process]?

This question was applied by the Federal Court when considering a Patent for the antipsychotic drug Aripiprazole.



A patented polymorph of Aripiprazole solved the problem of hygroscopicity associated with a prior crystalline form. Before the Patent was filed, a synthetic method was known that may have serendipitously led to formation of the polymorph, but synthesis of conventional anhydrous Aripiprazole of high hygroscopicity was also possible. Applying the above question, the Court held that a person skilled in the art would not necessarily be led directly as a matter of course to take the steps outlined in the prior art in the expectation that they would produce the polymorph. Accordingly, the polymorph invention was held to be non-obvious and therefore to possess an inventive step.

Patent protection is possible if the polymorph exhibits a surprising, unexpected or unique characteristic compared to what is already known. Importantly, there must be sufficient data included in the Patent Specification to illustrate the surprising characteristic and to clearly distinguish the polymorph from known polymorphs. If appropriate supporting test data can be collected, it is worthwhile considering speaking to a Patent Attorney.

Dr Carolyn Rolls MRACI and **Dr Jim Onishi** MRACI are patent and trade mark attorneys at Houlihan² Patent and Trade Mark Attorneys.



Carbon emissions are chilling the atmosphere 90 km above Antarctica, at the edge of space

View of noctilucent clouds from the International Space Station. NASA

While greenhouse gases are warming Earth's surface, they're also causing rapid cooling far above us, at the edge of space. In fact, the upper atmosphere about 90 kilometres above Antarctica is cooling at a rate ten times faster than the average warming at the planet's surface.

Our new research has precisely measured this cooling rate, and revealed an important discovery: a new four-year temperature cycle in the polar atmosphere. The results, based on 24 years of continuous measurements by Australian scientists in Antarctica, were published in two recent papers (doi.org/10.5194/acp-20-8691-2020).

The findings show Earth's upper atmosphere, in a region called the mesosphere, is extremely sensitive to rising greenhouse gas concentrations. This provides a new opportunity to monitor how well government interventions to reduce emissions are working.

Our project also monitors the spectacular natural phenomenon known as 'noctilucent' or 'night shining' clouds. While beautiful, the more frequent occurrence of these clouds is considered a bad sign for climate change.

Studying the 'airglow'

Since the 1990s, scientists at Australia's Davis research station have taken more than 600 000 measurements of the temperatures in the upper atmosphere above Antarctica. We've done this using spectrometers.

These instruments analyse the infrared glow radiating from hydroxyl molecules, which exist in a thin layer about 87 kilometres above Earth's surface. This 'airglow' allows us to measure the temperature in this part of the atmosphere.

Our results show that in the high atmosphere above Antarctica, carbon dioxide and other greenhouse gases do not have the warming effect they do in the lower atmosphere (by colliding with other molecules). Instead the excess energy is radiated to space, causing a cooling effect.

Our new research more accurately determines this cooling rate. Over 24 years, the upper atmosphere temperature has cooled by about 3°C, or 1.2°C per decade. That is about ten times greater than the average warming in the lower atmosphere – about 1.3°C over the past century.

Untangling natural signals

Rising greenhouse gas emissions are contributing to the temperature changes we recorded, but a number of other influences are also at play. These include the seasonal cycle (warmer in winter, colder in summer) and the sun's 11-year activity cycle (which involves quieter and more intense solar periods) in the mesosphere.

One challenge of the research was untangling all these merged 'signals' to work out the extent to which each was driving the changes we observed.

Surprisingly in this process, we discovered a new natural cycle

not previously identified in the polar upper atmosphere. This four-year cycle, which we called the Quasi-Quadrennial Oscillation (QO), saw temperatures vary by 3–4°C in the upper atmosphere.

Discovering this cycle was like stumbling across a gold nugget in a well-worked claim. More work is needed to determine its origin and full importance.

But the finding has big implications for climate modelling. The physics that drive this cycle are unlikely to be included in global models currently used to predict climate change. But a variation of 3–4°C every four years is a large signal to ignore.

We don't yet know what's driving the oscillation. But whatever the answer, it also seems to affect the winds, sea surface temperatures, atmospheric pressure and sea ice concentrations around Antarctica.

'Night shining' clouds

Our research also monitors how cooling temperatures are affecting the occurrence of noctilucent or 'night shining' clouds.

Noctilucent clouds are very rare – from Australian Antarctic stations we've recorded about ten observations since 1998. They occur at an altitude of about 80 kilometres in the polar regions during summer. You can only see them from the ground when the sun is below the horizon during twilight, but still shining on the high atmosphere.

The clouds appear as thin, pale blue, wavy filaments. They comprise ice crystals and require temperatures around –130°C

to form. While impressive, noctilucent clouds are considered a 'canary in the coalmine' of climate change. Further cooling of the upper atmosphere as a result of greenhouse gas emissions will likely lead to more frequent noctilucent clouds.

There is already some evidence the clouds are becoming brighter and more widespread in the Northern Hemisphere.

Measuring change

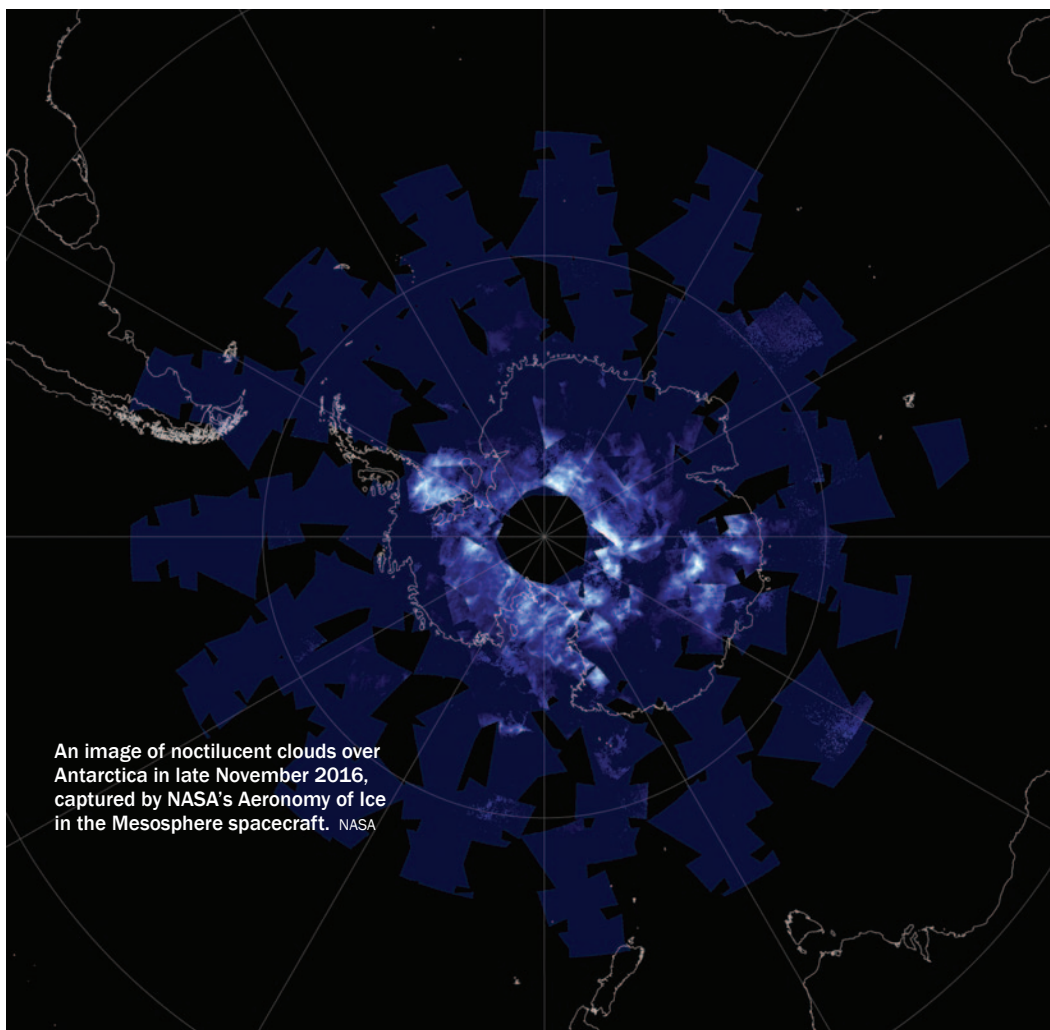
Human-induced climate change threatens to alter radically the conditions for life on our planet. Over the next several decades – less than one lifetime – the average global air temperature is expected to increase, bringing with it sea level rise, weather extremes and changes to ecosystems across the world.

Long-term monitoring is important to measure change and test and calibrate ever more complex climate models. Our results contribute to a global network of observations coordinated by the Network for Detection of Mesospheric Change for this purpose.

The accuracy of these models is critical to determining whether government and other interventions to curb climate change are indeed effective.

John French is atmospheric physicist, Australian Antarctic Division, and adjunct lecturer, University of Tasmania. **Andrew Klekociuk** is principal research scientist, Australian Antarctic Division, and adjunct senior lecturer, University of Tasmania. **Frank Multigan** is at the National University of Ireland Maynooth. First published at www.theconversation.com.

While impressive, noctilucent clouds are considered a 'canary in the coalmine' of climate change. Further cooling of the upper atmosphere as a result of greenhouse gas emissions will likely lead to more frequent noctilucent clouds.



A whiff of chemical harmony

'A strong background in chemistry works miracles', according to chemist turned perfumer Christophe Laudamiel. 'The mystery and myriad of scents found in perfumes actually have very rational explanations based on concepts such as volatilities, Van der Waals interactions, hydrogen bonds, and chemical reactions between alcohols, aldehydes, and amines', he explained when describing his career (bit.ly/312S0st).

Perfumers have argued that there is an essential equivalent to harmonious chords in music: namely harmonious vapour pressures.

Harmonious chords of the musical kind are observed to have vibration frequencies (pitches) that are proportional to simple ratios. For example, a triad is three notes, with intervals of a third between each, played or sung together. If there are large differences in frequencies, the ear separates them and harmony is considered lost, at least in traditional Western music. The chords are integrated into octaves for a complete musical effect.

The top note of a perfume's fragrance 'chord' is a very volatile group (vapour pressure 187–18 Pa, such as citrus). A second (13–2.7 Pa, such as jasmine) and third group (2.7–0.11 Pa, such as sandalwood) are the middle and bottom notes of the chord. They are all released and smelled sequentially.

In a basic distillation, the starting material can be heated to boiling in water rather than passing steam through it. It can then be extracted overnight in alcohol and strained to make a more concentrated starting point for steam distillation.

A good and readily available raw material is eucalyptus leaves. There are a large number of eucalyptus species, each with its unique fingerprint of chemicals in their leaves. The composition of each eucalypt type determines its usefulness for medicinal, industrial or perfumery purposes. Australia has an important and rich history of eucalypt distillation (bit.ly/3cXApI6 and bit.ly/35cXdL4).

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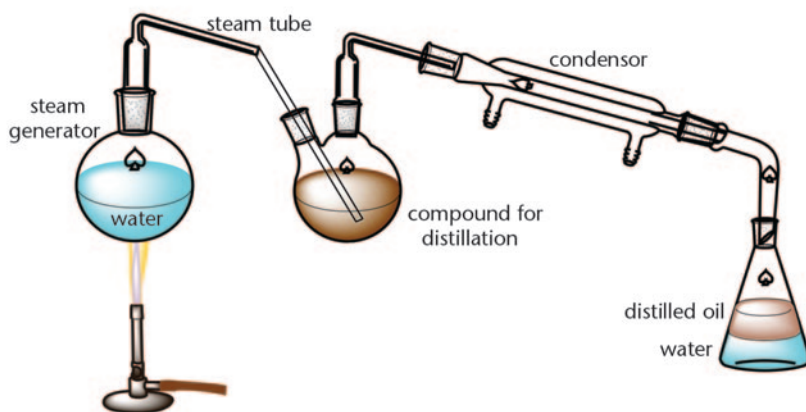


The fragrance wheel, based on a classification system developed by fragrance expert Michael Edwards. iStockphoto/MedejaJa

Most leaves, barks, fruit (peel) and the like are also good raw materials for distillation. Herbs such as rosemary, thyme and oregano work well. Most flowers do not. They are usually too delicate and the oil yields are very low and smell strange. The exceptions are lavender and roses. 'Stinking Roger' (Tagetes family, a weed) has a lot of oil in the leaves. Distillation times are usually reasonably short (due to modest boiling points).

So, what does the physical chemistry mentioned by Laudamiel boil down to?

- Water boils when its vapour pressure reaches atmospheric pressure and that is around 100°C depending on the current atmospheric pressure.
- Aqueous mixtures of liquids that are reasonably insoluble in water boil when the sum of their vapour pressures reaches atmospheric pressure.
- The higher the boiling point of the other liquid, the lower its vapour pressure at 100°C and the less it contributes to the distillate. Eucalyptus oil consists mainly of eucalyptol (1,8-cineol, b.p. 166–167°C).
- Many essential oils decompose before reaching their boiling points and this explains the advantage of steam distillation.
- A distillate may result in mainly water and little oil. If the oil is partially water soluble, and you throw out the water, you are literally throwing out the (baby) oil with the (bath) water! So a still that allows you to recycle the condensed water back into the pot overcomes this (see *J. Chem Educ.* 1988, vol. 65, p.92).



Many essential oils decompose before reaching their boiling points and this explains the advantage of steam distillation.

Equipment for steam distillation.

Modified from Selinger B., Barrow R. (2017) *Chemistry in the marketplace*. Reused with permission from CSIRO Publishing.

The exponential relationship between vapour pressure and temperature, described by the Clausius–Clapeyron equation, is important for perfume sales in different seasons and for different climates, and formulations differ accordingly.

The distillate products from leaves can be moderately toxic when ingested (e.g. eucalyptus and tea tree oils), and are labelled ‘poison’ in commercial products. In practice, toxicity depends on the dose. This toxicity can come from the secondary metabolites in the plant that it uses to protect itself from insect attack and microbial disease. The koala is unique in

being able to deal with the eucalypt leaf, its sole food (see Sept/Oct 2019 issue, p. 16).

And then there are those who assign magical protective and healing properties to such ‘natural’ products. Despite the claims, there is no evidence that eucalyptus essential oil vapour is a remedy for COVID-19 (bit.ly/2W2pqjG).

Ben Selinger FRACI CChem is Emeritus Professor of Chemistry at ANU. He appreciates the help now and in the past from John Lambeth, specialist fragrance designer extraordinaire.

Eau de camouflage

A friend told me he once designed a ‘fragrance’ for an enquiry from Asia that involved the idea of masking humans (mercenaries) in jungle combat situations by having them sprayed with a ‘jungle smell’. I interpreted this to mean earthy geosmin-like notes, mushroom, woody (patchouli) notes and green foliage/vegetable notes. The project came to nothing. This ‘fragrance’ was subsequently purchased in very large quantities for use to improve the smell of processed and aged chicken-manure-based fertiliser. Unfortunately a much higher dosage was required than the manufacturers could afford in order to mask or noticeably improve the diabolical smell of raw fertiliser.

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Protein stabilisation

White wines as well as some sparkling wines and rosé wines commonly have residual protein. This residual protein can lead to problems in the bottle, if the wine is not stored properly, as it can be readily denatured and lead to the formation of a brown haze. For example, if a wine is left in the car on a warm day, the internal temperature can rise to 45°C, leading to protein denaturing. The resulting brown haze is regarded by consumers as a quality defect, which affects acceptance of the wine and it may take time for the wine brand to regain consumer confidence. So it is common practice to treat the wine in advance, to stabilise it against protein haze formation.

Treatment with bentonite is perhaps the most common winemaking practice to achieve protein stability. Bentonite is an alumina-silicate for which the active component is montmorillonite. In essence, the alumina-silicate lattice has an overall negative charge with either sodium or calcium ions occupying the inter-lattice space. Both the sodium and calcium forms are used and both have their supporters and detractors. Protein removal occurs by ion exchange. Fortunately, the isoelectric point of most proteins in wine is such that they possess a positive charge at wine pH. Thus, the positively charged protein replaces the sodium or calcium cation and after mixing and settling, the bentonite-protein fluffy solid can be removed.

There are several difficulties and frustrations with the use of bentonite. First, from my own practical experience in wineries, it is an absolute pain to prepare the bentonite slurry and then to ensure its thorough mixing throughout the wine in tank. The bentonite-protein solid does not settle out properly in the bottom of the tank, leading to significant losses in wine volume, which is reflected in the amount available for sale. The negative impact of the bentonite on wine aroma and flavour is also the subject of on-going debate. In essence, bentonite eliminates the protein haze issue, but at a cost. This cost factor has stimulated the search for alternatives.

In a recent Wine Australia R&D newsletter entitled 'Is it good night for bentonite?', Dr Jacqui McRae from the University of Adelaide presented an update of some alternatives to bentonite (bit.ly/31qU0e7). In addition to getting the research aspect right, it is also necessary to gain regulatory approval for any new chemical or process that may be added to or used in wine. This needs to be done for the domestic and export markets, the latter being a potential minefield if there is not an existing international agreement regarding wine rules.

Carrageenan is a linear polysaccharide extracted from edible red seaweed. It is used in milk and brewing production as a means of achieving protein stabilisation. In a white wine trial comparing 11 different carrageenans, the *kappa* structural form was found to be effective in achieving protein stability without any negative sensory impact (*Aust. J. Grape Wine Res.* 2019, vol. 25, pp. 439–50). However, there is some question about the negative health effects of carrageenans in food production.

Polyphenols interact with protein. Grape seed powder, which



Creating a bentonite slurry for fining after wine pressing.

Robert Pitkin/CC BY-SA 2.0

is high in polyphenols, has been investigated for protein removal by additions to the juice. After fermentation, the wines were found to be protein stable. This strategy does seem a little curious to me, as a protein is sometimes used in white wine production to reduce the bitterness and astringency that results from polyphenols.

Dr McRae notes that flash pasteurisation may be effective. The process requires holding a juice at 80°C for about 30 seconds and then bringing the temperature back to normal 'in a flash'. While this technique is used more commonly to provide microbial stability, it could also produce heat stable wines. An extension of this approach utilises the addition of aspergillopepsin enzymes to the juice just before flash pasteurisation followed by fermentation. This generates a heat-stable wine (*Food Chem.* 2012, vol. 135, pp. 1157–65). The enzymes are approved for use in wine in Australia, but are of limited commercial availability at this stage.

The process that caught my eye and also that of our editor Sally is the potential for the use of magnetic nanoparticles. Agnieszka Mierczynska-Vasilev and colleagues from the Australian Wine Research Institute have described the application of acrylic acid plasma-coated magnetic nanoparticles for the 'rapid and selective removal of pathogenesis-related proteins' from wine (*Food Chem.* 2017, vol. 232, pp. 508–14). In essence, the prepared nanoparticles are added to wine, a short time (around 10 minutes) is allowed for protein adsorption and then the nanoparticles are removed: a hand-held magnet was used in the initial studies. The results indicated effective stabilisation towards haze formation. In a follow-up study (*Foods* 2020; doi:10.3390/foods9010001), the group found that up to ten adsorption/desorption cycles still allowed effective protein removal. The overall process had little impact on the composition of phenolic compounds and organic acids, important markers demonstrating minimal effect of the treatment on overall wine composition. Expect more to come from this exciting development.



Geoffrey R. Scollary FRACI CChem (scollary45@gmail.com) has been associated with the wine industry in production, teaching and research for the last 40 years. He now continues his wine research and writing at the University of Melbourne and the National Wine and Grape Industry Centre at Charles Sturt University.

Why do they call it that?

A buzz went through the historians of chemistry virtual gathering in July when it was reported to the CHEM-HIST list that a number of supposedly reliable sources report that benzine (what we call 'petrol' and the Americans call 'gasoline') was named after Karl Benz (1844–1929), whose patent for the first automobile was granted in 1886. The Benz car had a four-stroke engine with just one cylinder and the fuel was indeed 'benzine', a hydrocarbon fraction that had been available since about 1860 and was mainly used as a cleaning product. This benzine was a coal-tar product with a specific boiling range. Within a few years, the name was also adopted for a petroleum hydrocarbon fraction with more-or-less the same boiling range. The next higher fraction was called kerosene or sometime kerosine.

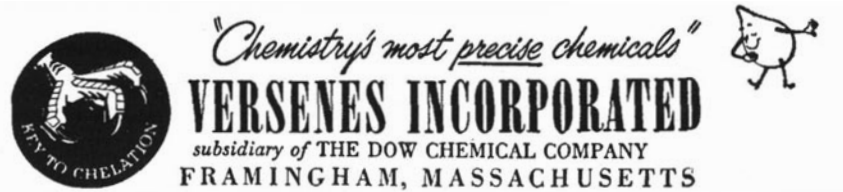
This all seemed pretty straightforward but other contributors to the list said that there was a longer history to it. It started with Eilhard Mitscherlich (1794–1863), who sent a manuscript with the title 'Ueber das Benzol' to the *Annalen der Pharmacie* and it was published in early 1834. A footnote revealed, however, that the editor, Justus von Liebig, had changed the name *benzin* that Professor Mitscherlich had given to the dangerous (possibly 'flammable?') oil that he had obtained by dry distillation of calcium benzoate, to *benzol*. Liebig had done this, he said, to avoid confusion of the chemical nature of the substance with the alkaloids that had names ending in 'in' and to align it instead with existing nomenclature for the acid (*Benzosäure*) and benzoyl compounds. Since Liebig was 'he who is to be obeyed' in the 19th century, most people accepted his dictum but in French publications such as those of Kekulé, there continued to appear benzine. Maybe it was just an example of the well-known French resistance to all things Allemand.

The lead for my second nomenclature puzzle is a report published by RACI *Proceedings* in 1955 of a talk given to the Analytical Group of the New South Wales Branch. The speaker was F.H. Conaghan and the talk was about the use of ethylenediaminetetraacetic acid (EDTA), a complexing agent used in analytical chemistry 'as a titrant in the volumetric determination of metals'. The end point in a titration was indicated by loss of the colour formed by an indicator with those metals ions that had not been gobbled up by EDTA.

EDTA featured strongly in Ben Selinger's article in *Chemistry in Australia*, just a year ago, when he wrote about crabby chemicals (Sept/Oct 2019, p. 38). Ben didn't mention titrations, but I guess that modern technologies like atomic absorption have swept away such primitive things as indicators that change colour, and maybe even burettes!

In his talk, Conaghan mentioned a number of indicators, but curiously not the *o*-nitrosophenols that were the subject of his 1956 PhD thesis at the University of New South Wales. The *o*-nitrosophenols were the centrepiece of a technical report

... 'Versenes' was not mentioned in the text. I guessed that it was a tradename for EDTA, and that turned out to be the case, but I had to dig a lot to satisfy my curiosity.



A 1955 advertisement for Versenes Incorporated.

written by Conaghan and published by his employer, the NSW Department of Mines, in the same year. The RACI report of Conaghan's talk was entitled 'The Use of Versenes in Chemical Analysis' but 'Versenes' was not mentioned in the text. I guessed that it was a tradename for EDTA, and that turned out to be the case, but I had to dig a lot to satisfy my curiosity. A method for the synthesis of EDTA was patented by a German inventor in the 1930s and marketed as Trilon B. Other manufacturers had already begun to market it under various tradenames. The Bersworth Chemical Company in the United States, founded about that time by Frederick Charles Bersworth (?–1973), marketed the sodium salt as Versene. After the company expanded its range to various salts and derivatives of EDTA, they adopted the plural and in 1952 changed the company name to Versenes Inc. In late 1954, the company was purchased by Dow Chemical and they still use the Versenes tradename today. Bersworth stayed with his company, now a Dow subsidiary, to make inventions relating to complexing agents. He took out more than 100 patents, the last of them being granted four months after he died.

It's a pity that we don't have the romance of Benz-ine, and nor was there any trace of Bers-ene ... but I do wonder if there was a V-for-B substitution back there in the 1930s. Or could it have been EDTA versus metal ions?



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*.

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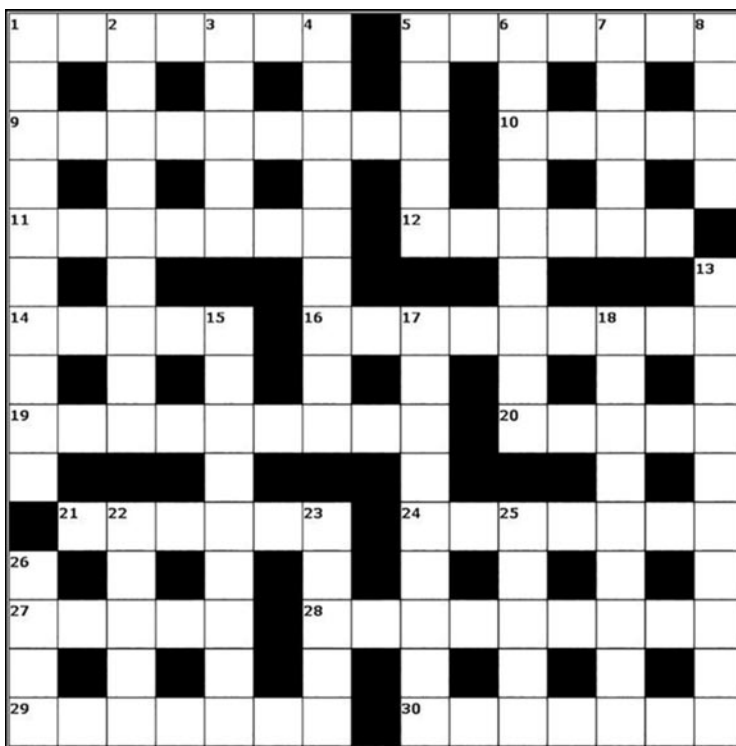
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Across

- 1 Took on antagonist. (7)
 5 Figure out a grim ad. (7)
 9 Societies adjust ratio following hoaxes. (9)
 10 Advantage holding sulfur photon, for example. (5)
 11 Concerning player pile. (7)
 12 Musical publications? (6)
 14 Sulfur by itself back to those characterised by C=C(OH). (5)
 16 & 28 Across Spoil a toxin video, damaged after flame leads to a very fast highly exothermic reaction. (9,9)
 19 My richest format? It's what I do. (9)
 20 New votes range. (5)
 21 Glosses over physical suffering taking time. (6)
 24 Alternatively use neodymium, tantalum and selenium with iodine. (7)
 27 Even nuisance calls conceal boredom. (5)
 28 See 16 Across.
 29 The main structure for $C_{34}H_{33}N_4O_5Fe$. (7)
 30 Limonene, for example, made Spooner a lively youth. (7)

Down

- 1 Rearrange 75, 58, 44, 27, 7, 6. It's happening! (10)
 2 N_5H on the plate? Zone out! (9)
 3 Abrupt brief. (5)
 4 Cleaner block. Germanium territory. (9)
 5 Admiral Zho's alternate description of two linked nitrogens at the terminal position. (5)
 6 Make us a biogum? It's cryptic. (9)
 7 Gum up decarboniser part. (5)
 8 Dig up what belongs to me. (4)
 13 Pence ended irrational reliance. (10)
 15 Investigator of its nicest concoction. (9)
 17 A 15 Down makes this spicy. (9)
 18 Change the form of meiosis adding rhenium. (9)
 22 The Hardy-Ramanujan Number held for a year. (5)
 23 Five elements put on display. (5)
 25 Way a mixture of gases goes up and down. (5)
 26 Connect helium and samarium differently. (4)

Graham Mulroney FRACI CChem is Emeritus Professor of Industry Education at RMIT University. Solution available online at Other resources.

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The competition is open to all BSc or equivalent Honours students of chemistry, chemical engineering or a related discipline attending an Australian university.

Competitors will be required to submit an essay describing the work conducted in their Honours project. They will be required to include contextual aspects of their project, key results and findings, and a discussion about the relevance and applicability of their work to the wider community, particularly the business and industrial community. They should comment if any of their work is being published in peer-reviewed scientific journals or is the subject of a patent application.

The essay should be approximately 2000 words in length but not longer than 4000 words. For more information about the application, please read the Award's judging criteria (at website below).

The essay should be submitted electronically as a Microsoft Word document to the Chair of the SCI Australia Group, Dr Richard Thwaites (Richard.thwaites@bigpond.com).

Up to three prizes will be awarded, valued at \$250, \$500 and \$750.

In addition, prize winners will be offered one year's free membership to SCI, which will include access to the monthly publication *Chemistry & Industry*, and be eligible to obtain other SCI publications at a substantial discount.

The top three winning articles will also be published at www.soci.org.

Applications deadline is 30 October 2020.

To apply and for information about judging criteria, visit www.soci.org/awards/society-prizes/australia-essay-competition.





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