Chemical Engineering Impact in Australia & New Zealand

VOLUME 3, 2022

IChemE ADVANCING CHEMICAL ENGINEERING WORLDWIDE

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The Institution of Chemical Engineers (IChemE) is a not-for-profit, member-led qualifying body and learned society for chemical, biochemical and process engineers, and the only organisation permitted to award the widely-recognised Chartered Chemical Engineer title and Professional Process Safety Engineer registration.

IChemE sets the standard for chemical engineering and process safety through a range of membership grades, registrations, publications and training for those seeking to improve their professional status, enhance their learning and network with peers.

Founded in 1922, IChemE has grown to over 30,000 members in more than 100 countries who are supported by a team of professional staff based in Australia, Malaysia, New Zealand, Singapore and the UK.

Australia represents 8% of IChemE's global membership base, making it the third largest on the international membership table.

Formation of a local IChemE association was established in the early 1960s. The Victorian Group of IChemE was formed in December 1962 and was closely followed by the establishment of the New South Wales and South Australian groups. In May 1967, the Australian State groups agreed to form the Australian National Committee, giving birth to the Institution of Chemical Engineers in Australia.

With this document we are pleased to present some recent highlights on chemical engineering research in Australia and New Zealand, and its positive impact on the way we live.

Foreword

This booklet brings together contributions from outstanding researchers across Australia and New Zealand, showcasing the real faces of chemical engineering research, and its impact on society in energy, education, environmental sustainability, water, healthcare and food technology.

As 2022 marks 100 years of the Institute of Chemical Engineers (IChemE), it's timely to reflect on how the profession has evolved from *a group who studied the art and science of chemical engineering and promoted chemical engineering vigorously*. Today, while the mission of the IChemE is similar, namely, *to advance chemical engineering's contribution to the benefit of society*, the profession itself has expanded and progressed to meet the shifting needs of society.

The case studies here range from water management, to regenerative medicine through to agriculture. Each of these very different studies has the common thread of delivering a creative, sustainable and viable solution to a complex problem.

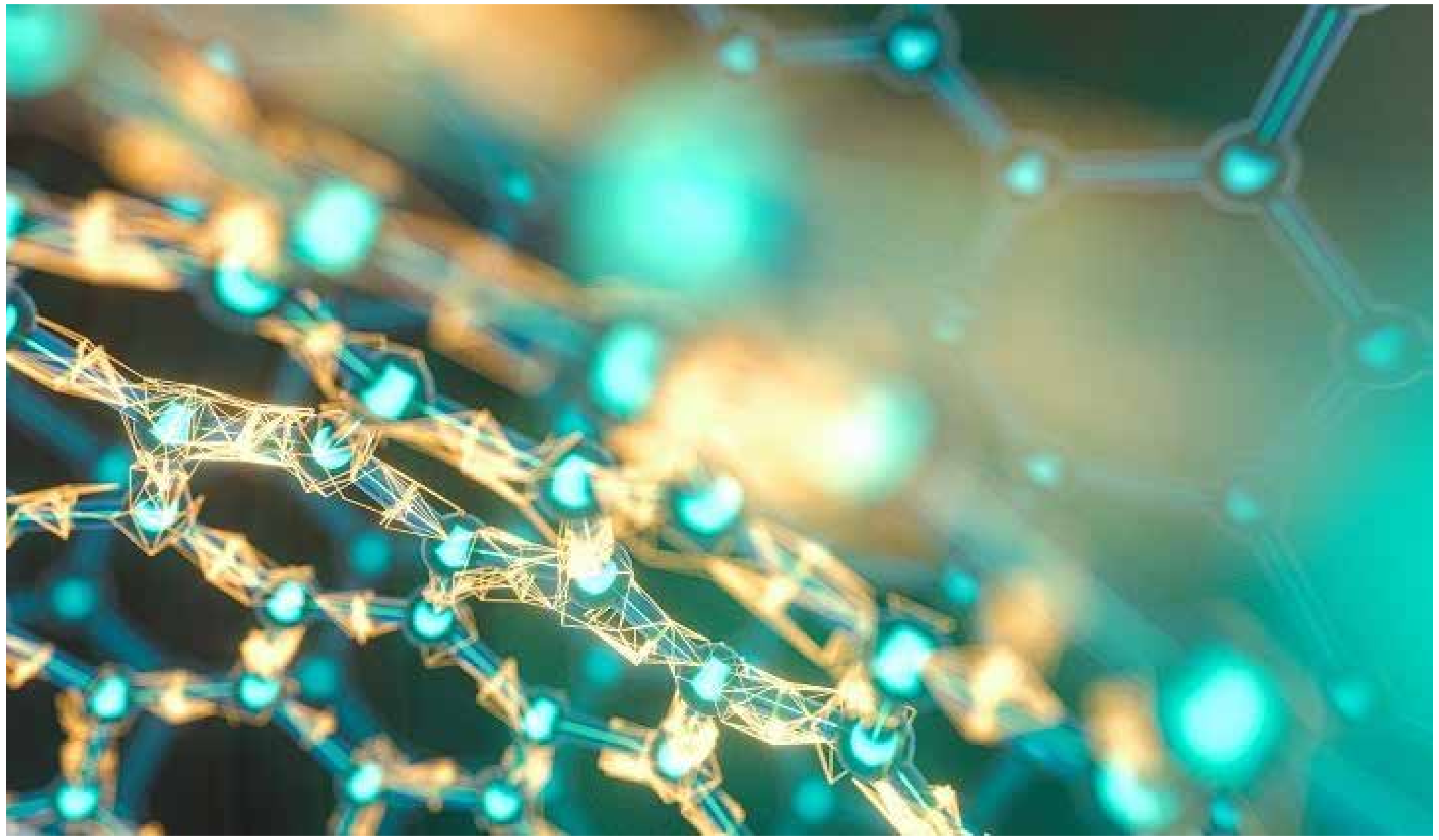
Chemical engineering has always been shaped by the challenges of the day, with its origins in responding to problems arising in some of the first chemical plants. Some of the very technologies that have advanced society and raised living standards are now causing the biggest headaches globally. Chemical engineers played a vital role in the rapid and ultimately unsustainable developments (for example, cheap energy and materials) of the last century. The new century of chemical engineering will be defined by being part of the net-zero and green chemicals revolution.

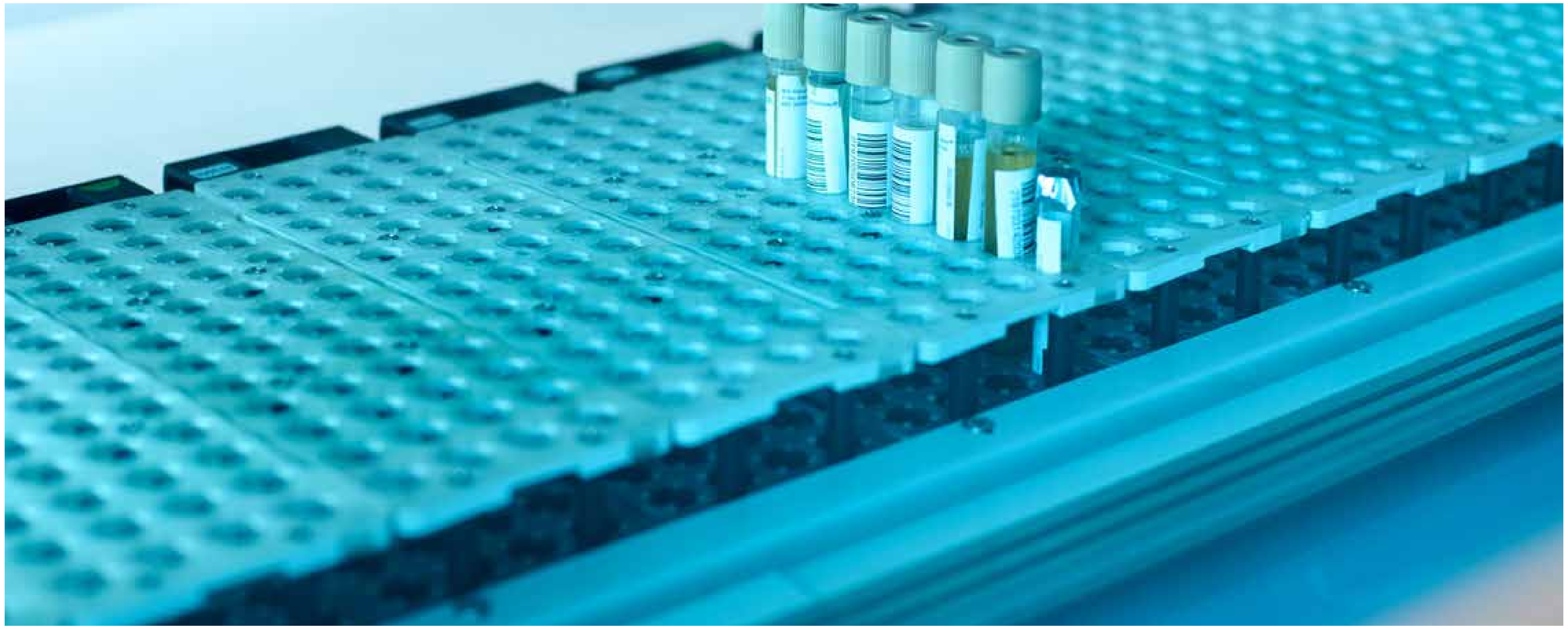
This year has again been marked by many difficulties, particularly in the university sector. As educators we have had to constantly pivot from online to face-to-face teaching, as researchers we have had limited access to laboratories, and as collaborators, very little opportunity to share and exchange our ideas. Coupled with the broader challenges facing the sector, I am proud and delighted to see the resilience and agility in our community.

We are once again pleased to present this booklet and believe the case studies outlined give us confidence that, despite the myriad complex problems that lie ahead, there are plenty of reasons to be hopeful.

I would like to take this opportunity to thank all the members of IChemE Research Working Group in Australia and New Zealand for driving this project, and Mr Peter Slane and Ms Natalie Angelone (IChemE, Australasia), IChemE Learned Society Committee (LSC) and Research and Innovation Community of Practice (R&I CoP) for supporting the initiative.

Associate Professor Akshat Tanksale
Project coordinator





Contents

Health

Collaborations among chemical and biological engineers, chemists and manufacturers have led to numerous major medical breakthroughs over many decades, not least of all the bulk manufacture of pharmaceuticals and the development of vaccines.

Chemical engineers apply their expertise to an array of health care applications, including supply of medical gasses, medical sensors and testing, and drug development and delivery.

The following two case studies from Monash University and Curtin University illustrate how chemical engineers responded to the COVID-19 pandemic, with agility, creativity, and dedication.

Development of a COVID-19 testing kit

What is the challenge?

In March 2020, the COVID-19 pandemic raced around the world leaving health care providers scrambling to test, trace and contain the spread.

As Australia went into hard lockdowns, a team of academics, clinicians from Monash Health, and PhD students agreed to pause their research projects and work together to develop a rapid and scalable COVID-19 serology test (detecting the antibodies raised in response to SARS-CoV-2 infection in blood) with the potential for rapid rollout. More than one year later the COVID-19 pandemic is still ongoing, and while vaccines are now available, diagnostic testing is still required to identify those who need to isolate, and for governments to make difficult decisions around lockdowns, which have significant socio-economic impacts.

Using the agglutination test as the starting point, the production of SARS-CoV-2 diagnostics only requires the substitution of the residual red blood cells (rRBCs) with bioconjugated cells. By producing bioconjugates of rhesus antibodies and peptides from SARS-CoV-2 spike protein, and immobilising these to rRBCs, the team successfully detected SARS-CoV-2 in the plasma of patients recently infected with SARS-CoV-2.

What is the impact?

This work illustrates how chemical engineering research has major direct and indirect roles to play in the current pandemic and illustrated the strength of cross-discipline and cross-industry collaboration, with a team of engineers and scientists working together to rapidly solve a complex problem.

> Facilitating accurate lab free testing would allow people to test themselves with absolute confidence, and thus limit the necessity for widespread lockdowns and quarantine, and the associated economic and social impacts.

Serology tests detect the antibodies produced in blood following infection with SARS-CoV-2 or vaccination against SARS-CoV-2. In contrast, the current testing method in Australia detects the virus directly, by detecting the genetic material of the virus from a sample taken from the nose or throat.

While RNA genetic material is present earlier in the infection compared to antibodies, it disappears once infection is over. Antibodies however, while taking longer to appear, stay relatively high for weeks or months, thus making it easier for authorities to manage the pandemic, including measures such as contact tracing, sero-surveillance, vaccine efficacy monitoring and so on.

How do chemical engineers contribute?

In March 2020, a team of chemical engineers from Monash University took up the challenge to develop new tests that were rapid, selective, and could be performed in remote locations or locations without access to tertiary hospital laboratories.

The team quickly identified that blood-typing agglutination tests were an excellent platform. These assays are performed world-wide prior to blood transfusions and in blood banks, using procedures suitable to the location and resource limitations. These assays can be performed by a single person with a simple centrifuge, or can be processed automatically by machines that run 24 hours a day. The supply chain for consumables and reagents is already robust world-wide, enabling rapid dissemination of the assay and related procedures.

Contributor: Dr Simon Corrie, Monash University, Australia

The research was a world first in demonstrating that blood-testing agglutination tests could be re-engineered to monitor the immune response to an infection. The team took some inspiration from related assays designed in the early days of the HIV epidemic in Melbourne.

Beyond COVID-19, these assays are inspiring new approaches to collect critical diagnostic information in a timely manner, with the goal of accurate and complete lab-free testing. If people could test themselves with absolute confidence, then social distancing and quarantine approaches could be extremely targeted, avoiding much of the economic and social impacts suffered around the world, not to mention limiting mortality and morbidity.

Additional to the direct impact on medical testing, the unique research team approach for this style of rapid prototyping has been invaluable and shows great promise for similar research projects. Typically, PhD students may collaborate, but they are primarily responsible for producing *individual and original* contributions in terms of papers and thesis chapters, limiting opportunities for team projects. However, the PhD students thoroughly enjoyed this opportunity, and felt that they learned a great deal in a very short time, honing their critical time/project management, communication and technical skills. The researchers are keenly looking at how to reproduce this team-based approach in the 'COVID-normal' future.

Building ventilators in response to COVID-19

What is the challenge?

Back in March 2020, daily news of COVID-19 wreaking havoc around the world painted a dire picture. As cases exploded across all continents, it became clear that capacity to treat those with severe illness would be stretched. Medical supplies were becoming limited and Australia's usual supply chains were not secure.

Australia did its own sums, which indicated that should we suffer a similar COVID-19 emergency here, as we saw play out elsewhere, our own supplies of equipment, including oxygen ventilators, would fall woefully short.

How do chemical engineers contribute?

Dr Tejas Bhatelia from Curtin University in Western Australia quickly understood the challenge. As a chemical engineer, Dr Bhatelia recognised that supplying oxygen to sick patients via a ventilator is at its core an engineering process; engineers know how to deliver fluids, and ventilators essentially deliver fluids (air and oxygen) to patients in a controlled manner.

Using commonly available equipment found in standard engineering laboratories, including mass flow controllers, pressure sensors and actuated valves, Dr Bhatelia gathered together a team of committed students from engineering, biomedicine, mechatronics and robotics. The team, mostly student volunteers, worked tirelessly to produce the first prototype in less than a week. The ventilators, called SAVER (Simple Available Ventilators for Emergency Response), were presented to doctors, respiratory experts and manufacturers for their input.

Within two weeks, the second prototype, incorporating the expert's feedback, was completed and met 75% of the criteria necessary to be TGA (Therapeutic Goods Administration) compliant. The ventilator has been designed as a modular unit with minimal parts and can be controlled with a tablet for remote operation.

A blueprint for version three is currently being developed.

What is the impact?

The SAVER ventilator is a first-of-its-kind system not seen anywhere else, and vastly lowers cost and increases the utility of the ventilator.

The project has demonstrated the ability of chemical engineers to quickly respond to a crisis in real time, making rapid decisions and constantly adapting approaches based on real world circumstances, for example, the availability of spare parts.

The ability to manufacture such critical life-saving equipment locally will also open avenues for local business.

Within a few short weeks, a group of researchers, mostly students, volunteered their time and worked around the clock to design a medically functional emergency ventilator. Happily, Australia did not need them at the time. With closed international borders the country was spared the worst and ICU hospitalisations were kept to a minimum. However, circumstances can change quickly, and having home grown design and manufacturing knowhow is the best kind of insurance policy when global supply chains run dry.

Noteworthy also is the impact on the students involved, who displayed the very best of the profession they are entering. By applying their new skills to a crisis, thinking laterally in multidisciplinary teams, working long hours with no payment other than cups of coffee, is a humble and timely reminder that our future is in safe hands.

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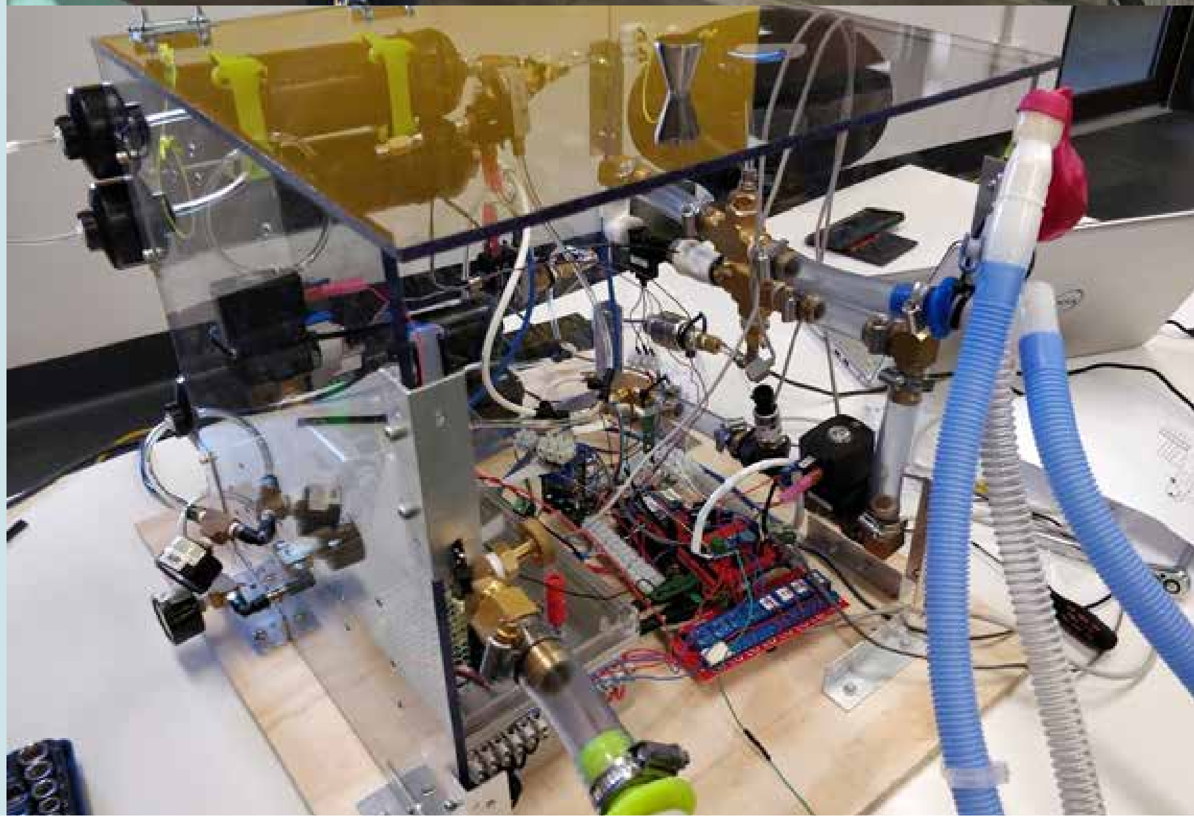


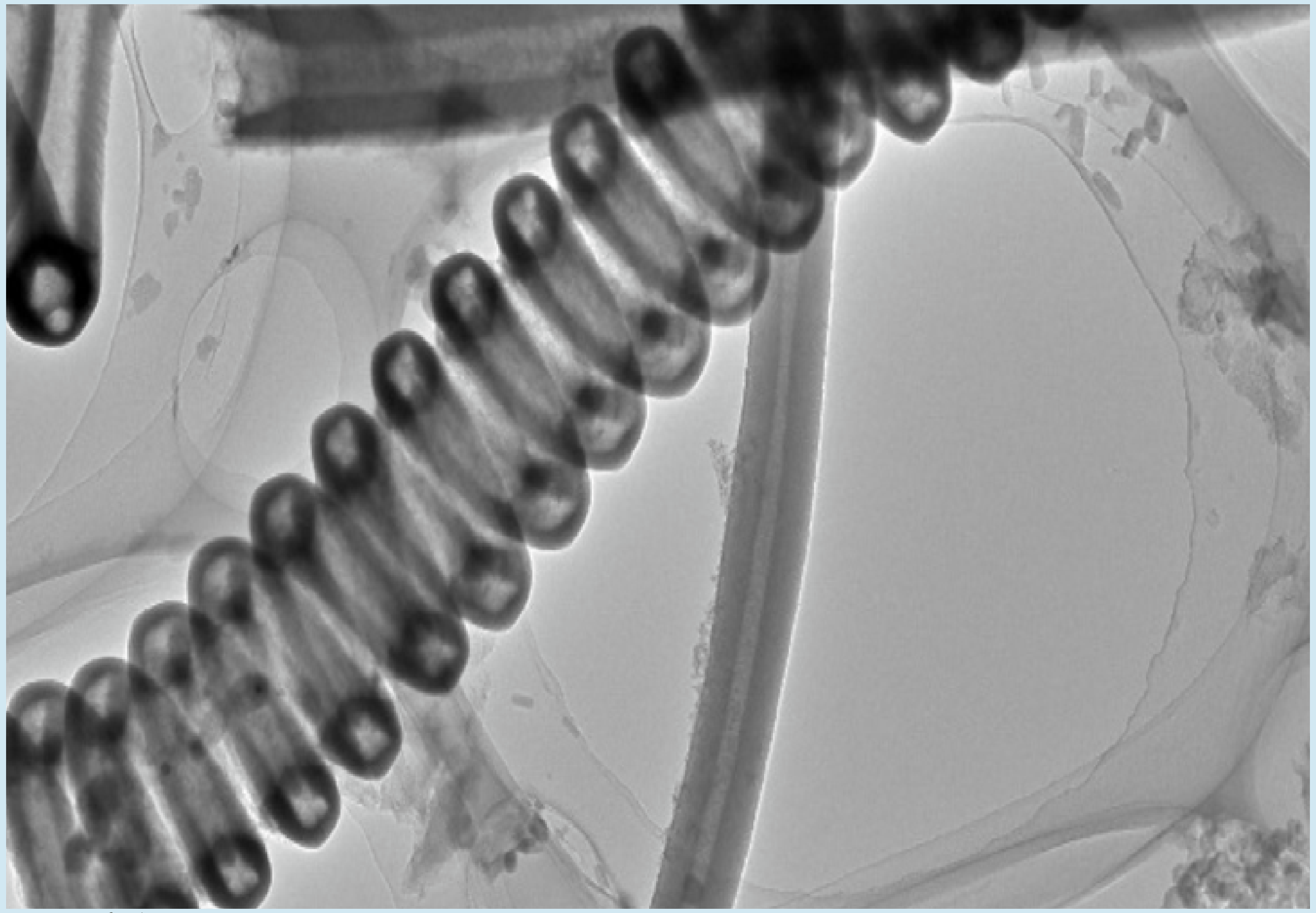
Contributor: Dr Tejas Bhatelia, Curtin University, Australia

Food & Water

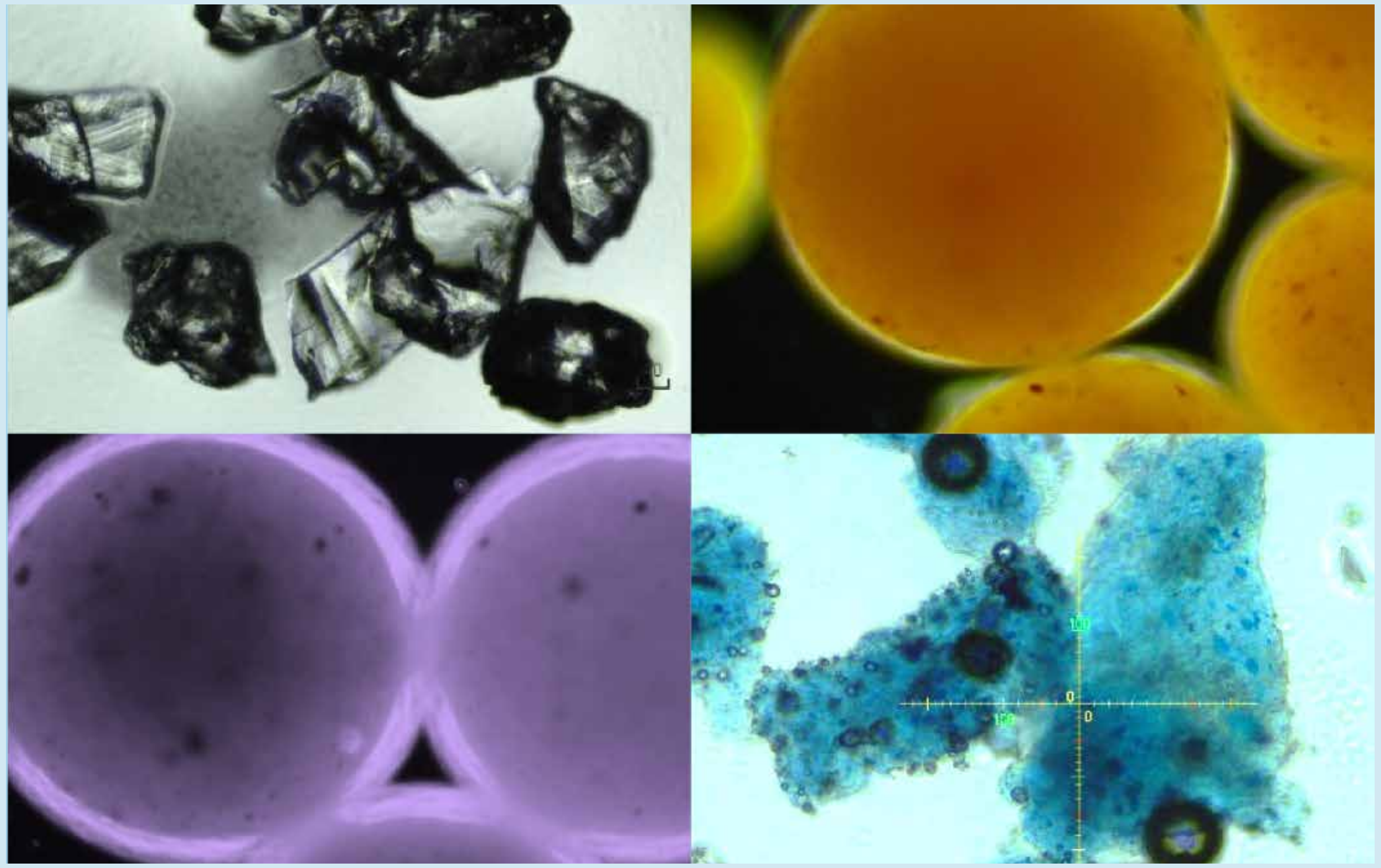
From paddock to shop to plate to disposal, chemical engineers are involved in almost every aspect of the food and water cycle. Fertilisers, food processing, packaging, and waste and water management are improved and advanced through chemical engineering.

With the multiple complex challenges of climate change, plastic waste, water scarcity and population growth, creative solutions are needed like never before.

Showcased here are four examples of how chemical engineering research is applied to meet some of these challenges.



TEM images of Carbon Nanosprings



Breaking down marine plastic with nanosprings

What is the challenge?

Water security and sustainability have been, and will always be, ongoing key challenges in Australia, where freshwater is scarce. Australia's freshwater supply of surface and groundwater is constantly under threat from drought, bushfires, soil run-off, and wastes including micro/nano-plastics and batteries. Added to this, overuse and abuse of antibiotics lead to bioaccumulation, drug resistance and environmental toxicity, bacteria and COVID virus contaminations are placing our already precious resource under strain.

Inevitably, the waste pollution finds its way into oceans and rivers posing a global environmental threat with harmful consequences on human health and ecosystems.

How do chemical engineers contribute?

Professor Shaobin Wang and Dr Xiaoguang Duan from The University of Adelaide are developing safe, fast, and highly efficient water purification technologies based on tiny coil-shaped carbon-based magnets. Using functional nanomaterials manufactured from biomass and plastics as low-cost green catalysts, the team developed Advanced Oxidation Processes (AOPs) as green remediation systems. The technology employs green peroxides to generate highly reactive species such as free radicals and singlet oxygen.

The high purification performance and the quick reaction kinetics of this process are the formula for success when it comes to eliminating hazardous contaminants. Wang and Duan have successfully used the technology to purify the microscopic plastic debris from everyday cosmetics (toothpaste, shower gel, and facial cleansers) and associated secondary micropollutants (additives and plasticisers) in sewage wastewater. They recently used the target-oriented AOPs system to remove harmful microorganisms in drinking water.

The group has secured several research grants to develop functional materials for next-generation water purification technology that is environmentally friendly, less expensive, highly efficient, and intelligent. The carbon nanosprings are strong and robust enough to break microplastics down into harmless compounds for removing in water or upgrading into value-added produces toward a circular carbon economy.

What is the impact?

This catalytic technology will be used to purify hazardous micropollutants, particularly the refractory microplastics in wastewater, preventing their entry into rivers and oceans. The green and safe technology also holds great promise for application in purification of drugs and antibiotics as well as disinfection of airborne germs, bacteria, and COVID-19 virus in ventilated air and wastewater from quarantine hotels, clinics, and hospitals.

Research is underway to manufacture small and integrated devices to be implemented on sites for rapid decontamination, sterilisation, and disinfection purposes. Also, the technology is promising to couple with the existing wastewater treatment plants for advanced treatment to guarantee drink water safety and to meet the criteria for discharging treated wastewater into natural systems without secondary contamination.

This technology also holds great promise for application in the disinfection of airborne germs, bacteria, and COVID-19 virus in ventilated air, and wastewater from quarantine hotels, clinics, and hospitals.

Contributors: Professor Shaobin Wang and Dr Xiaoguang Duan, School of Chemical Engineering and Advanced Materials, The University of Adelaide, Australia

Maple syrup in New Zealand

What is the challenge?

New Zealand has the right climate and conditions to produce the delightfully delicious maple syrup, at least theoretically.

While traditional production requires mature trees, recent research in the United States suggests that densely planted saplings can produce far more maple sap per hectare than mature trees. This plantation method involves production of maple saplings as a row crop, with harvesting in late winter. This unique winter seasonal harvest also allows for the earlier mobilisation of New Zealand's seasonal workforce that typically works on vineyards and fruit crops.

The successful realisation of maple plantations provides an alternative, higher-value use for marginal land, supports regional development, and produces an exportable product. Coppice pruning reduces the time to first harvest significantly (down to 4 - 7 years) and vacuum harvesting ensures a sustainable and reliable production. The income per hectare for maple syrup compares favourably with vineyards, and out-performs other land-uses (e.g. sheep, dairy, pine).

However, progress and investment in this opportunity is being hampered by a lack of understanding of sap exudation mechanisms in each species – especially under New Zealand's milder climatic conditions. This knowledge gap limits the ability to predict potential yields, optimise new production systems, confirm economic viability, and identify new sources of tree syrup.

How do chemical engineers contribute?

Professor Matthew Watson and colleagues from the University of Canterbury are using advanced imaging techniques to observe sap flow in living trees. At the Imaging and Medical Beamline at the Australian Synchrotron, the researchers could undertake the immensely challenging task of imaging live trees at the resolution required to observe sap flow mechanisms at a cellular resolution. Through advanced, high-resolution, 3D, *in-vivo* imaging techniques, the team have achieved a world first in non-destructively imaging the microstructural changes that occur during freeze-thaw cycles in maple trees.

The team have also modelled the temperature distribution inside trees under New Zealand's milder climate and found that smaller trees experience more freeze-thaw cycles than large mature trees. Freeze thaw cycles are correlated to sap yield, therefore using densely planted trees with stunted growth from coppice pruning will result in a higher sap yield in New Zealand. A test plantation near Hanmer Springs in New Zealand has been established for ongoing monitoring.

Microstructural observations, augmented with data from instrumented trees on the test plantations, will be used to refine an advanced sap flow model, and generate predictive tools to accurately forecast maple syrup yield under various climatic conditions and differing harvesting techniques.

What is the impact?

Professor Watson and his colleagues are currently working with several landowners around New Zealand to establish additional test plantations. While the research has not yet been commercialised, initial estimates indicate that minimum viable crop size and sap-to-syrup conversion facility is about five hectares. The long-term vision is to establish 2,000 hectares of row-crop tree sap plantations in New Zealand to create a world-scale tree syrup export business. Two thousand hectares of sap production is projected to generate NZ$60 million/year in export revenues.

New Zealand's potential as a maple syrup producer is being tested by researchers at the University of Canterbury.

Contributor: Professor Matthew Watson, The University of Canterbury, New Zealand

Supercritical UV for disinfection of fluids with low light transmittance

What is the challenge?

Ultraviolet disinfection is commonly used in wastewater applications as the final step before discharge to the receiving environment. Traditional systems typically require the water to be of a relatively high clarity for disinfection. This clarity is referred to as UV transmittance, where 100% represents clear water. Typical 'submerged bulb' systems generally require a UV transmittance (UVT) of at least 60% to provide adequate disinfection, although lower levels are possible with some designs. However, to achieve a UVT of even 30% in wastewater can be challenging for industrial effluents, or where municipal systems contain a high amount of trade waste, thereby requiring additional costly upfront treatment, such as chemical dosing.

UV light is absorbed very quickly in liquids. According to the Beer-Lambert law, this decrease in UV light intensity is exponentially related to the depth of the liquid, meaning the thicker the liquid depth, the lower the UV light intensity. This loss of effective UV light intensity becomes highly pronounced as it passes through low UVT liquids.

In New Zealand, as with many other countries, there is a constant pressure to upgrade water quality due to stringent regulations driven by environmental, ecological, and public health concerns. The New Zealand government has set a target to have 80% of all large rivers and lakes to a 'swimmable' water quality by 2030, leading to increasing requirement for disinfection in discharge consents.

How do chemical engineers contribute?

UV disinfection is relatively low cost when compared to alternative treatments and can provide high disinfection efficiency of bacteria and viruses. Moreover, compared to alternatives like chlorine, UV does not react with organic material in effluents to produce toxic by-products. UV light is produced by special lamps that emit light within the UV spectrum. Typically, for the standard low-pressure UV lamps, this is UVc light predominantly at the germicidal wavelength of 254nm. A traditional 'submerged bulb' UV system involves configuring these lamps in an array submerged within the liquid flow.

The new start-up NovoLabs Limited, run by Massey University's Professor Andy Shilton (Managing Director) and Dr Matt Sells (NovoLabs Chief Operating Officer), has a novel (patent pending) technology for achieving UV disinfection of liquids with UVT well below 40%. This approach is called *Supercritical UV disinfection*. The device triggers a very thin but very fast-moving flow of liquid in an open channel. This type of flow hydraulics has a Froude number of >1 and is known as supercritical flow. The liquid is only a few millimetres in depth, which ensures high intensity UV light penetration throughout, while the high velocity of the supercritical flow maintains a high flow throughput. Instead of having the bulbs submerged in the channel, the bulbs irradiate the UV light down into the liquid from above the treatment channel (inset image to the right).

What is the impact?

NovoLabs has pending patents in seven jurisdictions worldwide.

In a case study to demonstrate its effectiveness, NovoLabs worked with The Manawatu District Council. The council spends hundreds of thousands of dollars each year on chemicals to improve the UVT of their effluent to enable their traditional submerged bulb UV system to meet their < 1,000 MPN/100mL *E. coli* consent for land irrigation. NovoLabs supercritical UV device was tested and found to consistently achieve an *E. coli* concentration below 1,000 MPN/100mL without any prior chemical treatment. This was estimated to have the potential to save the rate payers $1,000 NZD per day in operating costs.

NovoLabs is already working with several companies, including two food processing industries. Supercritical UV has been tested and proved highly effective at treating their effluents despite the liquids having UVT's less than 1%, which is not normally considered viable for UV effluent treatment.

NovoLabs believes Supercritical UV technology has a wide range of applications in process industries including preventing microbial growth in general process liquids and extending the shelf life of liquid foods and beverages.

As seen in the main image (right), NovoLabs technology consists of a series of treatment modules arranged in a rack. This allows the system to be easily scaled or upgraded by adding or removing modules.

The individual modules operate in parallel. With the PLC control, this parallel operation means that any single module can be taken offline and the flow throughput will be maintained through the rest of the system. One of the many benefits of this design is that in the event of a UV lamp failure (all lamps have a limited lifespan) the system will sense this outage and automatically switch flow to another treatment module, thereby mitigating risk to performance consistency.

Access to the treatment modules is simple, quick, and clean. The individual modules are designed to slide out of the rack, and, with a flip up lid, access into the treatment area is possible within seconds. The inlet and outlet of each module is designed to allow this sliding movement without disconnection from the system, allowing for a no drip, no mess access to the treatment channel.

NovoLabs plans to initially offer its supercritical UV technology throughout Australasia and then springboard into the multibillion-dollar global UV disinfection market.

Contributors: Professor Andy Shilton, Massey University, New Zealand and Dr Matt Sells Novolabs Limited, New Zealand

UV disinfection is relatively low cost when compared to alternative treatments and can provide high disinfection efficiency of bacteria and viruses, and, unlike alternatives like chlorine, UV does not react with organic material in effluents to produce toxic by-products.

Inside view of the supercritical UV device. Two UV bulbs are in the lid seen at the top of the photo, with the supercritical flow in the open channel at the bottom of the photo (left), racked 8-module supercritical UV system (below).

Cell based meat production

What is the challenge?

According to estimates compiled by the Food and Agriculture Organization (FAO), the world will need to feed nine billion people by 2050. A business as usual approach will not be sufficient to meet this target, and would place too great a burden on our already vulnerable natural resources. To sufficiently and equitably nourish the world's population, we need to revolutionise the way we produce and manage food, including adapting our diets, reducing food waste and modifying our farming techniques.

Another critical tool to feeding the world is to diversify protein supply with sustainable and nutritious options. Plant based proteins and cellular agriculture have many benefits, including, economic, public health and environmental.

Produced through cellular agriculture, cultivated meat is grown directly from cells, and is often also referred to as cultivated meat, cultured meat and lab-grown meat.

Over the past decade the field of cultivated meat and seafood has greatly accelerated around the world, with the production price dropping dramatically. In 2020, Singapore was the first country to approve a cultured meat product for human consumption with many products in the regulatory pipeline. These signs suggest that product commercialisation could occur within the next decade. The social acceptance, uptake and production of these products will vary internationally.

How do chemical engineers contribute?

Dr Laura Domigan from the University of Auckland is leading a new project (NZ$3 million within the Government's MBIE Catalyst: Strategic – New Zealand-Singapore Future Foods Research Program) to understand cultured meat and its use for the development of new hybrid foods. This research is focused on three key areas: (i) sourcing muscle stem cells from high health status New Zealand livestock, including cow, sheep, deer and pig; (ii) characterising a hybrid (livestock cell + plant protein) food matrix, which includes characterising the interactions within the food matrix itself, as well as assessing the contribution of cultured livestock cells to nutritional and organoleptic properties; and (iii) investigating policy and regulatory implications.

What is the impact?

The outcomes of this research are essential to inform regulatory bodies and policymakers about the safety and efficacy of these new food products and will provide both New Zealand and international industry with the scientific understanding of this new transformational technology.

The team are also working closely with the existing New Zealand agricultural industry, including farmers and food companies, to ensure sustained benefit to New Zealand.

> A critical tool to feeding the world is to diversify protein supply with sustainable and nutritious options.

Contributor: Dr Laura Domigan, University of Auckland, New Zealand

Environment & sustainability

Concern for the environment and sustainable use of the Earth's resources is now the guiding priority of much of chemical engineering research.

Remediation of polluted waterways, cleaning up the supply chains, and exploring feasible and economical ways ahead for a circular economy are all ways in which chemical engineers are making a difference.

Presented here are several case studies from Australia and New Zealand, including harvesting energy from wastewater, low polluting fertilisers and cleaning up containments in the Great Barrier Reef.

Zero energy sewage treatment

What is the challenge?

Comprehensive energy and greenhouse audits of wastewater treatment plants have been conducted by peak bodies around the world, including the International Water Association, Water Environment Research Foundation, and the Australian Water Association. Unsurprisingly, the results highlight that sewage and water treatment plants are energy-intensive and account for up to 40% of municipal energy consumption.

To highlight a local example, SA Water is the second biggest energy user in South Australia and across Australia's utilities' providers, energy is usually the second-highest operating cost, behind labour.

However, sewage contains a substantial amount of latent chemical energy, equivalent to approximately 5 KJ/L or five times the energy required for the entire sewage treatment process. Current treatment plants use anaerobic digesters to produce biogas from sewage sludge, but the energy recovered is typically only 5-7% of the energy available in raw sewage.

How do chemical engineers contribute?

A large consortium, led by researchers from The University of Queensland (UQ), has successfully demonstrated zero-energy sewage treatment in a pilot plant using novel free nitrous acid (FNA) technology.

The FNA biotechnology increases energy recovery, while achieving regulatory nutrient discharge standards by using the nitrite pathway. Selecting for the nitrite pathway (over the nitrate pathway) saves 25% energy demand for nitrification and 40% carbon demand for denitrification. Therefore, an upfront carbon separation unit (e.g. a primary settler) can be used to divert a substantial fraction of wastewater organics to an anaerobic digester, more than doubling biogas production. The bioenergy (biogas) recovered is estimated to completely offset the energy consumption for sewage treatment, achieved by harnessing the energy contained within the treated waste.

The nitrite pathway is a heavily researched topic, but despite three decades of international research and development, the processes have been plagued with challenges - the suppression of nitrite-oxidising bacteria (NOB), which oxidise nitrite to nitrate, being the greatest one. In a world first, the UQ-led consortium made the breakthrough discovery that free nitrous acid (FNA or HNO_2) inactivates NOB to successfully overcome this barrier.

What is the impact?

A consortium of nine partners[1] from across Australia, including the Queensland Government, three universities (urban and regional), four major urban utilities from three States, and a regional water authority, demonstrates the scale of this project and demand from the water industry for this innovative solution. Over the course of three years, the project team successfully implemented the technology at the pilot-scale, removing nitrogen via the nitrite pathway to <5 mgN/L, with effluent from a primary settler. This is a world-first, achieved by linking scientific excellence and industry know-how.

The FNA biotechnology achieves multiple water management objectives at little cost, including maximising organic matter conversion to biogas and decreasing energy consumption, while still achieving efficient nitrogen removal from sewage.

The system offers benefits to wastewater treatment plants (WWTPs) of all sizes and configurations; it is flexible enough to be applied to both large and small sewage treatment plants across metropolitan and regional communities, with a payback time of just 3-5 years. The pilot plant and modelling studies confirm that a large WWTP can save $1-4M per annum using this technology, with low capital expenditure. In addition, FNA treatment enables further energy savings from decreased sludge viscosity. Small WWTPs can save thousands of dollars per annum, also benefiting from improved effluent quality, and biosolids stabilisation through enhanced sludge degradability and improved volatile solids destruction.

Australia produces about 226 GWh of energy from sludge biogas per annum. Extensive modelling and scale-up analyses based on pilot-plant results show that the FNA technology triples bioenergy production from sewage sludge. Therefore, if the FNA technology was applied to the current biogas-generating treatment plants in Australia, production would increase to over 678 GWh per annum, equivalent to the energy used by about 46,000 homes pa, and potentially avoiding the use of more than 83,000 tonnes of black coal.

The project has drawn significant strategic investment with commercialisation of the FNA technology being managed by UQ's commercial arm, Uniquest, with two listed, transnational corporations.

In further recognition of the importance of the research outcomes to the water industry, this project won the very competitive Australian Water Association Queensland R&D Excellence Award in 2020.

With Australia's population growing by about 1.4% per annum (according to the Australian Bureau of Statistcs), water utilities are under pressure to increase treatment capacity and improve effluent quality at least cost. However, major infrastructure upgrades require substantial capital investment. In contrast, the FNA biotechnology presents a retro-fitting opportunity operated at ambient temperature and pressure, enabling water utilities to avoid unnecessary major capital works, thus achieving significant economic and environmental benefits for the community and region.

Contributors: Professor Zhiguo Yuan, Dr Shihu Hu, The University of Queensland

[1]Project collaborators: Queensland Government, The University of Queensland, Southern Cross University, Urban Utilities, City of Gold Coast, Wide Bay Water Corporation, South Australia Water Corporation, Water Corporation of Western Australia, University of Technology Sydney

Sewage contains a substantial amount of latent and unused chemical energy, equivalent to approximately five times the energy required for the entire sewage treatment process. Current treatment plants typically use only 5-7% of the energy available in raw sewage. New technology from the University of Queensland and its industry partners will not only make treatment plants energy neutral, but turn them into net energy producers.

Developing controlled release fertilisers with improved efficiency

What is the challenge?

Within modern agricultural practice, fertiliser application has become essential to maintain and increase productivity in New Zealand's agricultural sectors. However, poor nutrient management and application practice is having an unsustainable and deleterious effect on the environment. Moreover, farmers in New Zealand are currently applying fertiliser at rates greater than plant requirements to cover losses to leaching and volatilization to N_2O/NH_3.

New Zealand's fresh water is under pressure. Eutrophication from nitrogen and phosphorus run-off from agricultural and horticultural land is threatening native species and creates a value disconnect between urban and rural communities.

Currently, global fertiliser demand is ~190 million tonnes per annum, supporting food production to feed the world. In New Zealand, fertiliser use of ~2 million tonnes per annum (NZ$1.6b) underpins primary productivity, including dairy, meat, wool, wine and horticulture, delivering a value exceeding NZ$25 billion.

However, New Zealand's fresh water is under pressure. Eutrophication from nitrogen and phosphorus run-off from agricultural and horticultural land is threatening native species and creates a value disconnect between urban and rural communities. In many catchments, conventional fertilisers used by farmers is restricted via permissible nitrogen leaching limits.

How do chemical engineers contribute?

A project led by Professor Clive Davies from Massey University is working on a two-phase solution: improve the fertiliser and optimise the application. Novel fertiliser formulations use lignite, a significant resource in New Zealand, as the 'carrier'. The team are taking a novel approach to the development and systematic testing of controlled release fertilisers for each of the principal plant nutrient elements, Nitrogen (N), Phosphorus (P), and Potassium (K). The formulations, currently the subject of patent applications, have the potential to address major environmental problems, such as water pollution, by reducing nutrient run-off, and greenhouse gas emissions by limiting microbial breakdown products from nitrogenous fertilisers.

Central to this research is the application of lysimeter experiments. Although time and resource intensive, lysimeter experiments with *in situ* sensors facilitate the measurement of nutrient transport and uptake processes under controlled conditions. This technique is useful for studying the plants themselves or in this case the performance characteristics of the fertilisers. They are an important step between laboratory analysis and field trials.

Based on the results from 3-month lysimeter experiments, fertiliser formulations are adjusted, allowing up to four times more trials compared to conventional field trials. The comprehensive environmental control implemented in these lysimeters allows for precise repeatability not found in conventional lysimeter systems.

What is the impact?

Sustainable fertiliser application could facilitate the increased export of primary products and deliver much of the growth required to meet the New Zealand Government's stated aim of doubling export value by 2025.

This research addresses low fertiliser efficiency resulting from the loss of nutrients to the environment and the associated loss of productivity of farmers and growers. Low fertiliser efficiency also has a negative impact on the environment through pollution of waterways and greenhouse gas emissions. These are topical issues with many New Zealand waterways now deemed unsafe for swimming and the country facing a large cost to meet greenhouse gas reduction obligations.

Contributor: Professor Clive Davies, Massey University, New Zealand

Contaminants in waters of the Great Barrier Reef

What is the challenge?

There are many thousands of synthetic contaminants in our waterways that are seldom monitored, often unregulated, yet with the potential to severely impact aquatic environments and surrounding ecosystems. Examples include PFAS forever chemicals, antibiotics and anti-depressants, and personal care products such as fragrances and sunscreens. Many of these chemicals end up in our sewage and wastewater, and in the absence of effective treatment and removal, are released into the environment.

The 2015 National Environmental Science Program (NESP) Report found a number of contaminants were detected in the waters of the Great Barrier Reef (GBR). Adjacent to the GBR, Townsville City Council releases treated effluent, via its wastewater treatment plant, into Cleveland Bay, which is home to turtles and dugongs.

Also of significant ecological concern is the impact of antibiotics in the wastewater. Antibiotic resistant genes are making their way into the environment and potentially impacting on local turtle populations.

Antibiotic resistance is one of the world's greatest emerging threats, with predictions that it will lead to 10 million human deaths by 2050.

How do chemical engineers contribute?

In collaboration with Townsville City Council (TCC), James Cook University (JCU) researchers are identifying these contaminants in sewage and treated effluent. In the waters of Cleveland Bay, they are quantifying how effective the Council's process is at removing contaminants, and seeking to better understand the environmental risk of such contaminants.

PhD student Laura Kuskopf and her supervisor Associate Professor Madoc Sheehan from JCU are collaborating with the TCC, several testing laboratories, and other universities and research organisations to sample and test sewage and treated effluent for the highest risk contaminants.

To evaluate the potential environmental risk posed by municipal contaminants of emerging concern (CECs), it is necessary to understand which CECs are present in discharging wastewater, how they will be sampled and quantified, and which CECs are the most concerning regarding ecological risk.

To achieve this, the team have developed a Sampling Analysis and Quality Plan (SAQP). This tool can be used to critically review and detail the strategy that will be adopted to effectively capture and monitor the CECs.

In developing the SAQP, the researchers quantified a sufficiently comprehensive array of CECs from different chemical classes to validate their presence or absence in wastewaters at a local sewage treatment plant. They then highlighted the contaminants considered most likely to pose a risk to the receiving environment, based on current scientific knowledge. They have advised their local council and will employ a sampling rationale appropriate to the target contaminants.

After detecting more than 50 contaminants in treated effluent, a priority list of the riskiest contaminants is currently being developed to track and understand their impact in Cleveland Bay.

What is the impact?

This research will help councils to better protect the iconic species of the inshore marine environment of the GBR and help determine the effectiveness of the TCC's state of the art treatment technology (membrane bioreactor) in reducing environmental risk. This will help other councils with less-effective treatment systems to improve their processes.

In a testament to the significance of this work to the region, Laura Kuskopft's recent publication won the Australian Water Association's Best Water e-Journal Paper 2020 at the Ozwater21 Industry awards night.

To evaluate the risk posed by municipal contaminants of emerging concern, it is necessary to understand ecological risk.

Contributor: Associate Professor Madoc Sheehan, James Cook University, Townsville, Australia and Townsville City Council, Australia

PFAS remediation technologies

What is the challenge?

PFAS, or Per- and poly- fluoroalkyl substances, are synthetic chemicals consisting of a completely or partially fluorinated alkyl chain. The hydrophobicity of the alkyl chain makes PFAS desirable for a range of applications. The main application of PFAS were in the fire-fighting foam produced by 3M©. As the carbon-fluorine bond is extremely stable and not easily susceptible to thermal degradation, this chemical quickly became the product of choice by firefighters across the world to produce a stable foam to douse fire. However, the long term use of this chemical over the past several decades has resulted in severe land contamination. The chemical has also permeated groundwater.

The key characteristics of PFAS, which led to its widespread application, i.e. the stability, has now become the main headache for water and waste-water treatment plant operators. The chemical is extremely stable and resistant to microbial and chemical degradation and hence PFAS often persist in the environment long after their intended application. The widespread distribution of PFAS in the environment has led to public exposure through food consumption, drinking water, and dust inhalation.

The Australian Government has identified numerous sites around the country contaminated with PFAS. The effects are widespread, socially disruptive and negatively impact the perception of safety for entire regions. Several governments have taken steps to minimise or restrict the use of PFAS containing chemicals. However, legacy issues remain a problem.

In addition to the existing legacy problems, a new source of PFAS has been also identified that continues to inject PFAS in the environment and water system via leaching of landfills. The historical widespread use of PFAS in household consumer products means that Australian landfills have become point sources for these compounds. PFAS were detected in the leachate of all 22 landfills that were sampled across in 2015[1] and it is suspected that many more landfill sites must be releasing PFAS which are yet to be investigated. Brisbane alone has more than 160 landfill sites that are closed but continue to produce leachates.

How do chemical engineers contribute?

University of Queensland (UQ) researcher Dr Pradeep Shukla is developing technology for groundwater and landfill remediation to separate and destroy PFAS from the water system.

The technology to remediate polluted ground and surface requires two key processes: (i) capture and concentrate, and (ii) the destruction of concentrated toxic pollutants.

The most significant and difficult issue for rehabilitation of trace toxins is access: i.e. the ability to concentrate them to the point where the volumes of material requiring treatment, either through destruction or long-term storage, is manageable. Since the cost of destruction or long-term storage effectively scales linearly with volume, the concentration of the contaminated water is a critical economic consideration. The established methods of concentration for low-level water contaminants are sorption/desorption, ion exchange and membrane filtration.

While several technologies are currently under research and development globally, at UQ, Dr Shukla's team is developing an alternative technology to separate PFAS, called the *Foam Fractionation* process. This process is a low energy technology that can remove PFAS by bubbling air through the polluted water. As PFAS are highly hydrophobic chemicals, they are removed in the foam phase, which can then be collected and subsequently destroyed.

The second key aspect of this research is plasma destruction of concentrated PFAS. There are currently no suitable destruction techniques for PFAS, although chemical and electrochemical oxidation methods using ozone, peroxides or dithionite and sulphite have been reported.

Oxidizing plasmas, which are commonly used to destroy toxic and clinical waste, are often viewed as a potential process destroying waste in milliseconds. However, the process seems to be ineffective for PFAS as the electro-negative fluorine species cannot be oxidised. Flue gas clean-up e.g. by adsorption is then necessary to capture the toxic end-products and the contaminated adsorbents need to be disposed of in secure landfills, which makes the process unnecessarily expensive.

The UQ group is developing a novel oxidative/reductive plasma. The proposed novel plasma system has a unique combination of oxidising and reducing agents in the turbulent flame zone where the PFAS is broken down and all fluorine species are reduced. The acid gas produced may be easily removed from the exit gas stream by lime scrubbing, thus producing simple and non-toxic by-products such as calcium fluoride and calcium sulphate.

What is the impact?

The social, environmental and health impacts of PFAS are well-documented and the economic impost of PFAS contamination is extremely high and has long term effects.

The current and sole commercial technology available for PFAS remediation from groundwater is adsorption on activated carbon which is not only expensive, but also requires dumping and long-term landfill storage, simply transferring the problem from one site to the other. Furthermore, the carbon adsorption process cannot be used to treat high toxic pollutant matrices such as landfill leachates, which will be the main source of PFAS from legacy landfill sites for years to come.

The technology being developed in this project provides the complete and safe destruction of PFAS to harmless end products at a much lower cost, including the most difficult pollutant, i.e. landfill leachates.

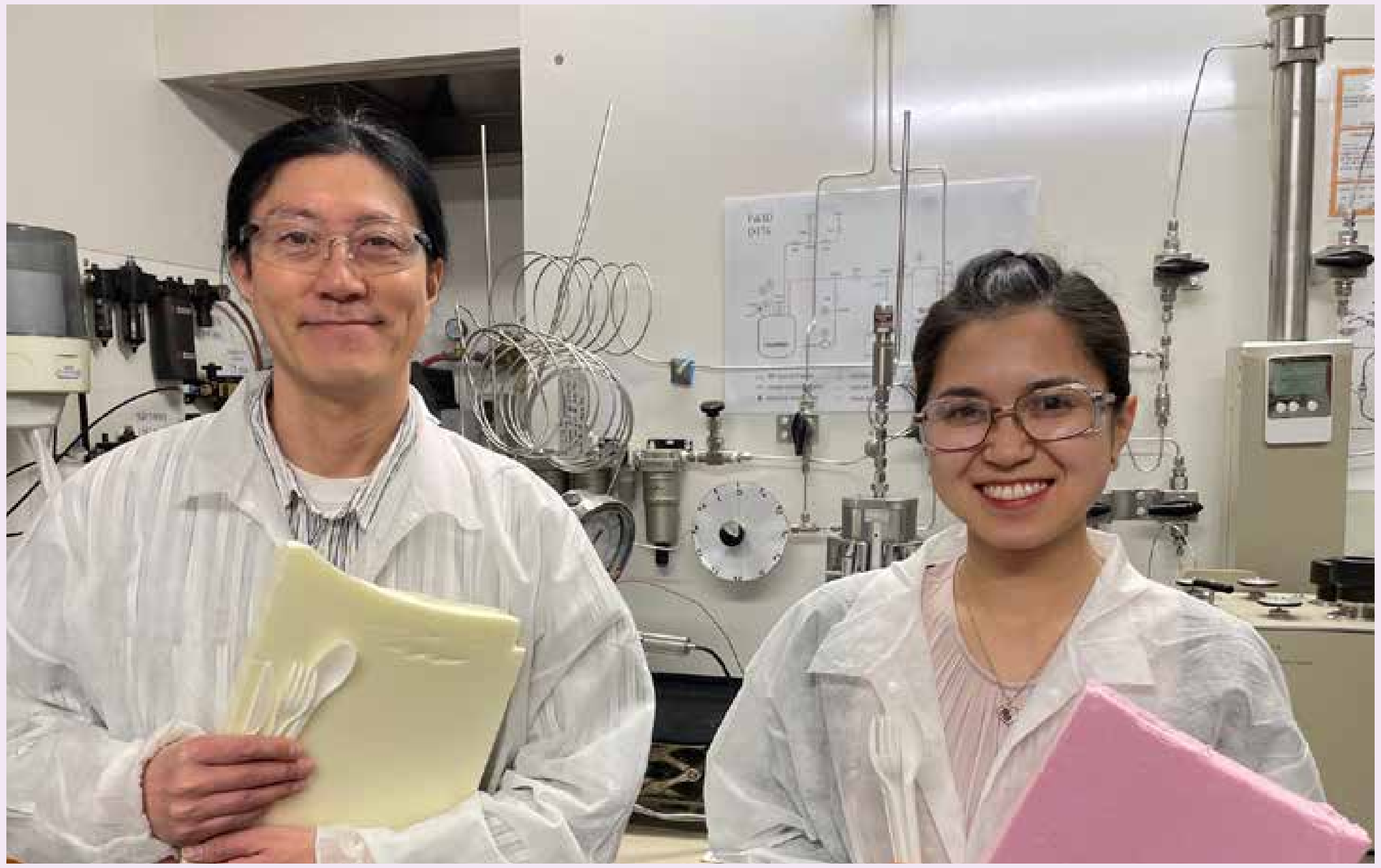
The UQ team are currently developing a field demonstration plant that will be installed at the landfill site to treat the landfill leachates thus capturing and destroying the PFAS at the point of source. The technology is of interest to several industry groups as well as government organisations, including the Department of Defence, Queensland Urban Utilities, Brisbane City Council, and other councils and water corporations in Australia.

This research aims to deliver a tangible technology that can be implemented to help the councils, water corporations and other industry to manage the legacy issues associated with PFAS.

The Foam Fractionation process is a low energy technology that can remove PFAS by bubbling air through the polluted water. As PFAS are highly hydrophobic chemicals, they are removed in the foam phase, which can then be collected and subsequently destroyed.

Contributor: Dr Pradeep Shukla, The University of Queensland, Australia

[1]Galen et al, 2016. Occurrence and distribution of brominated flame retardants andperfluoroalkyl substances in Australian landfill leachate and biosolids. Journal of Hazardous Materials 312 (2016) 55–64



Recycling the non-recyclable

What is the challenge?

We cannot imagine our lives without plastic, rubber and other synthetic materials. They are safe, convenient and hygienic, a factor brought sharply into focus during the COVID-19 pandemic. However, we have only minimal knowledge regarding their end of life cycle.

Currently, plastics contaminate our food sources, pollute our ecosystems and cause untold damage to wildlife. It is scandalous that despite many governments now mandating the end of single use plastic, approximately half the production of plastics is still used for single-use applications.

Unfortunately, we are not equipped to manage all the polymer wastes that are disposed intentionally or accidentally into our environments. As non-biodegradable materials, plastics can be only be fragmented into smaller microplastics.

Currently, biodegradable plastics provide a possible solution. However, biodegradable plastics are not recycled in most countries including New Zealand as they are designed to degrade – i.e. break down thus compromising mechanical strength – and should therefore be disposed in regular rubbish bins. Biodegradability has been introduced to the plastic industry in order to minimise adverse impacts of plastic waste in the environment, although it would be more constructive to develop methods to recycle biodegradable plastics or develop recyclable biodegradable plastics.

As recyclable plastics degrade during physical recycling, the mechanical strength of the end product needs to be considered. It is not practical or favourable to recycle biodegradable cutlery back into cutlery due to lowered strength after recycling. Recycling one plastic product to another application is also challenging as each product is made of a grade specifically suitable for each application. For example, a grade for producing cutlery may not be used to make films or foams.

How do chemical engineers contribute?

Dr Heon Park and colleagues from the University of Canterbury, New Zealand, are investigating cutlery made of poly(lactic acid) or polylactide (PLA) and its conversion potential in to foams, in which mechanical strength is not crucial. PLA is the most successfully adopted synthetic bio-based plastic in the industry and has been the focus of a large body of research into applications including three-dimensional (3D) printing, fabrics, packaging/bottles, films, automotive, electronics, and tissue engineering. Moreover, its properties are similar to various non-degradable plastics. More than 200,000 patents have been already published, and this polymer is still actively studied.

Using PLA cutlery, readily available in a local supermarket, as a model of biodegradable plastic, the research group employed supercritical fluid (SCF) to physically foam the PLA cutlery rather than chemical foaming, thus avoiding the use of toxic chemicals. They applied supercritical carbon dioxide (SC-CO_2) as a physical blowing agent to foam PLA cutlery as CO_2 is non-toxic and easy to reuse. The study determined the effects of temperature, pressure, and pressure drop rate on the foamed structure to ensure it is possible to foam PLA cutlery to various foam structures for different applications.

Using PLA cutlery available in a local supermarket, the research group employed supercritical fluid (SCF) to physically foam the PLA cutlery rather than chemical foaming.

What is the impact?

The advances made possible through chemical engineering have led to some of the biggest challenges facing human kind, including climate change and mountains of plastic waste. However, the creativity and know-how of chemical engineering researches can and will play a leading role in finding solutions to these complex problems.

The COVID-19 pandemic has clearly shown that we cannot live without plastics, especially disposable ones. Thus, we need new technologies to reuse, recycle, or even upcycle disposable plastic products urgently. This research has shown that even disposable plastics can be reformed for different applications.

The successful application of this research could result in new business streams for recycling biodegradable plastic to produce foams using an environmentally benign method.

Contributor: Dr Heon Park, The University of Canterbury, New Zealand

Busting pharmaceutical waste with water

In New Zealand 30-40 tonnes of toxic pharmaceutical waste are collected annually, autoclaved at 134°C and disposed of at landfill sites. The potential environmental and ecological impacts is unclear.

What is the challenge?

Pharmaceutical waste, including used and unused expired prescription drugs, personal care products, and over the counter medications, represents a highly toxic and recalcitrant waste stream that is currently entering our natural systems unmonitored and without sufficient treatment. Even at low concentrations, many pharmaceuticals are potentially toxic to humans. Moreover, continuous discharge of drugs into the environment may lead to lifelong exposure of numerous organisms to these chemicals.

Toxic contamination risk also arises from seized illegal drugs entering the waste stream untreated, including methamphetamine, heroin, cocaine, LSD, and MDMA. It is a growing problem. In 2019, New Zealand Customs saw a 17,000% increase in drug seizures compared with 2015. Currently, up to 10 tonnes of seized drugs are disposed of in New Zealand's landfills at high cost.

Regulations and controls over the pharmaceutical waste stream vary around the world, however technical solutions are lacking. Improper management and insufficient awareness, training and monetary resources make pharmaceutical waste management an emerging problem.

In New Zealand currently, 30-40 tonnes per annum of toxic pharmaceutical waste are collected through the District Health Board take-back schemes. They are autoclaved at 134°C and disposed of at landfill sites. In the case of seized drugs, they are encapsulated in concrete, untreated, before disposal at landfills. This will not deconstruct medicines, and they remain in toxic forms within the environment. This can lead to the contamination of drinking, surface, and ground waters. These wastes are potent, concentrated and bioactive chemicals, with little discussion about the environmental and ecological impacts.

Industries, including utility companies, pharmaceutical manufacturers, professional bodies, pharmacists, clinicians, veterinary suppliers, waste management organisations and local councils all recognise the problem but are cautious about taking ownership due to potential liabilities and lack of economically viable solutions.

High temperature incineration (900-1,200°C) is the only practical alternative. This is prohibited in NZ under the National Environmental Standards for air quality, due to emission of dioxins, furans, and particulate matter. New Zealand's commitment to the Basel Convention on the Transboundary Movements of Hazardous Wastes and their Disposal requires hazardous wastes to be disposed of, wherever possible, in their country of origin. New Zealand chemotherapy (cytotoxic) drugs are currently incinerated off-shore. Traditionally NZ has justified the export of hazardous waste as the only viable option due to scale and the economics of establishing treatment facilities. The option of exporting waste is becoming uncertain, with increasing restrictions on processing foreign waste, as we have seen with the China plastic waste import ban in 2018.

How do chemical engineers contribute?

Associate Professor Saeid Baroutian and his team in the Waste and Resource Recovery Research Group (WaRe^3) at the University of Auckland have created a network of academics, medical professionals and commercial partners working together to develop a portfolio of innovative pharmaceutical waste management technologies.

They have developed a novel catalytic hydrothermal deconstruction system that can process recalcitrant pharmaceutical wastes. This technology will significantly change the environmental, social and fiscal value equation to provide a solution that meets stakeholder requirements and lead to the elimination of the more than 30 tonnes per annum of pharmaceutical waste going to landfill through the take-back schemes.

The mechanism of catalytic hydrothermal deconstruction involves the formation of hydroxyl free radicals on the catalyst. A series of free radical reactions break down pharmaceutical wastes to aldehydes, ketones, and carboxylic acids. Carboxylic acids in the presence of oxygen further break down into carbon dioxide and water. In tests conducted for the degradation of a variety of medicines, hydrothermal treatment completely deconstructed antibiotics, hormones, and anaesthetics to water, CO_2, and acetic acid within ten minutes.

Pharmaceutical waste brings with it the packaging materials such as plastics, paper and cardboard associated with its use. They found that packaging materials such as polyethylene, polyethylene terephthalate, polypropylene and paper can also be completely degraded using this technology.

What is the impact?

The high temperature catalytic hydrothermal processing technology has the advantage of being scalable (right-sized) and clean (using only water) with low energy input (200-300°C) and therefore low operational costs. It will provide the foundation for a new industry in New Zealand for collection and disposal of toxic pharmaceutical waste and illegal and seized drugs.

The research team have been working closely with key stakeholders along the pharmaceutical waste lifecycle, including pharmaceutical manufacturers, district health boards and waste management companies to fully understand the technology needs and consider how the new technology will be integrated into established practices. Industry partners are looking to establish a pilot hydrothermal deconstruction plant for pharmaceutical waste and seized illegal drugs. Once established, the system can be expanded to veterinary clinics and for the disposal of industrial hazardous waste. This partnership with end-users offered a deep sector knowledge, established international networks and export channels to the international markets. The export of this new technology will ultimately enable extension of improved waste solution systems to other countries.

COVID-19

The pandemic has impacted the handling and disposal of medical waste. A surge of regulated medical waste has overburdened networks of hospitals, waste management companies and disposal facilities. Medical waste generated from the COVID-19 outbreak includes PPE such as gloves, gowns, face masks, face shield and respirators. One of the unknown risk exposures to public health safety from COVID-19 is the treatment and disposal of PPE waste. The team are now evaluating the use of hydrothermal deconstruction process for the decomposition and valorisation of PPE waste generated in the response to COVID-19.

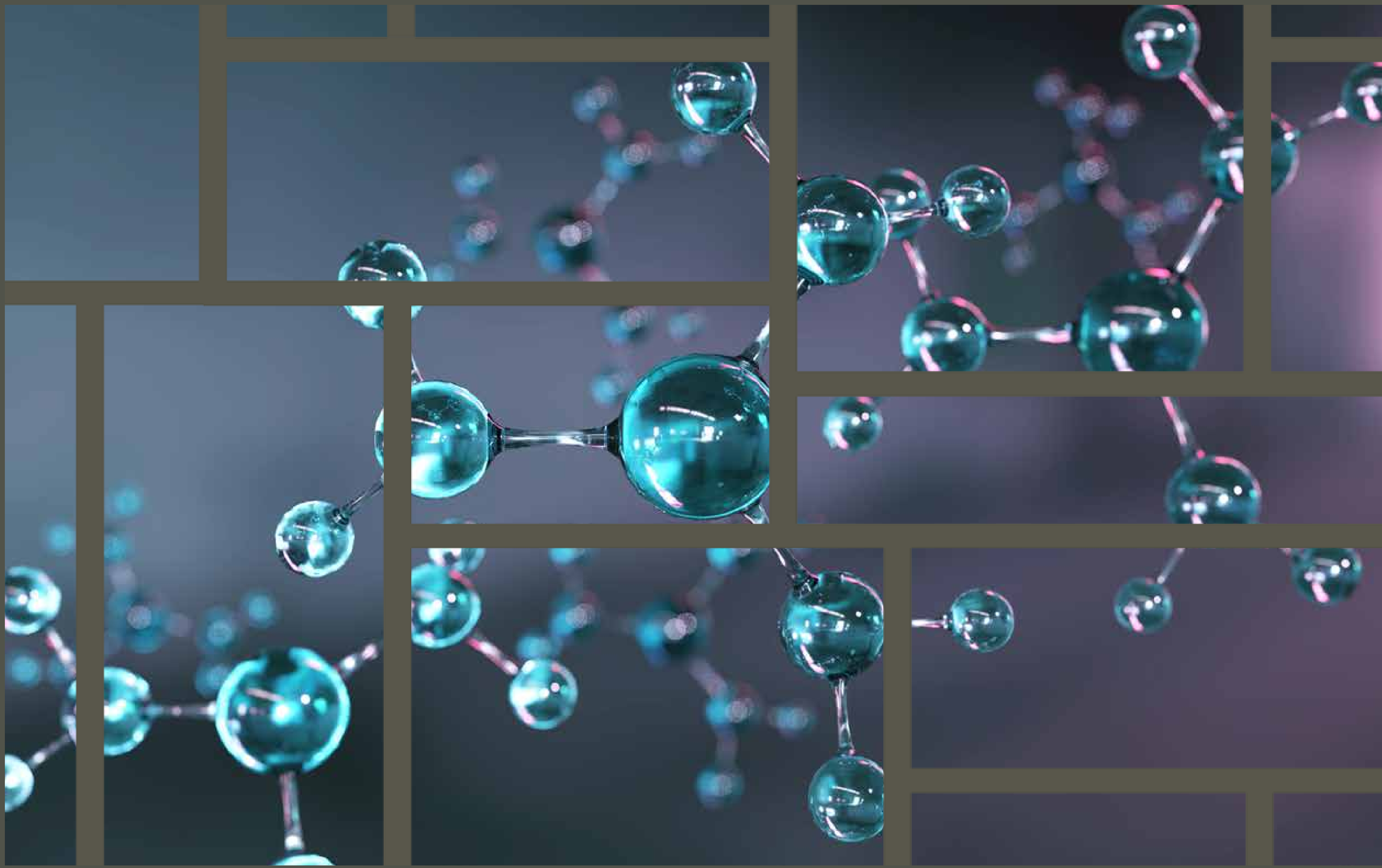
Contributor: Associate Professor Saeid Baroutian, The University of Auckland, New Zealand

Materials

Chemical engineers research materials for myriad applications, from clean energy and medical devices to textiles and functional nanomaterials.

Researchers investigate the properties of different substances and how their unique characteristics can be manipulated to create revolutionary new materials.

Showcased in the following pages are examples of research into sustainable medical tissues for surgical implants, improving the wearability of bullet-proof vests, and the development of functional materials for biological applications.



From animal materials or waste products to high value surgical materials

What is the challenge?

Tissue damage from sports injuries, disease and trauma sometimes requires surgical intervention and repair of soft tissues using grafted material.

Anatomical repairs can be made to tissues such as damaged tendons, hernia and abdominal wall reconstructions, heart valves, and reconstruction in breast and vaginal surgery. These soft tissue implants are referred to as medical devices, a term most often associated with machines and other physical equipment.

As standards and rates in medicine and health care vastly improve around the world, the challenge is providing enough extra materials for surgical implants and minimising reliance on living donors or the patients themselves.

Worldwide, tens of millions of reconstruction or repair operations are carried out, with the global medical scaffold technology market alone is valued at USD 1.1 billion (2020).

How do chemical engineers contribute?

Professor Richard Haverkamp from Massey University in New Zealand applies new and powerful techniques to discern previously unknown detailed structural information of materials, using instrumentation available at the Australian Synchrotron in Melbourne and the neutron facility at the Australian Nuclear Science and Technology (ANSTO) precinct in Sydney.

His team is creating soft material scaffolds, based on collagen derived from animals, with the cellular material of the donor animal removed. Removing this material eliminates the risk of rejection as the host cells recognise the collagen and elastin material as their own. By studying the characteristics of the collagen, the team has gained an insight into how these materials can be made strong, or supple, or elastic, with the specific mechanical properties needed for each application.

What is the impact?

The research has a direct impact on the medical devices industry and has arisen directly through requests for product development. As with all medical technology, suppliers need a thorough understanding of the performance of their devices and the fundamental structural reasons behind this performance. In this way the industry is able to build better products and therefore enhance their business through the application of fundamental science and engineering.

The team has worked with several companies in Australia, New Zealand and the USA, both to assist in the development of knowledge and technology that contributes to new patented devices, and to inform the development, improvement and better understanding of existing devices. Through these research-industry collaborations, not only are solutions to complex problems found, but fundamental science is advanced through a greater understanding of the hierarchical structure of collagen in the medical biomaterials.

By understanding the architecture of the collagen fibrils, engineers and scientists can explore any structure-function relationships and work closely with an industry partner to optimise the final product. For example, through synchrotron studies Professor Haverkamp's team have identified a structure strength relationship where material strength increases with increased alignment of the collagen fibrils in the plane of a material. Or in a further example, tightly packed collagen molecules create stiffer materials - stiffness increasing with collagen density. By applying this knowledge, it is possible to manipulate processing methods to produce a material with highly aligned collagen fibrils, or chemically control the packing of the collagen molecules, thus making a stronger material or a stiffer or softer material and optimising patient outcomes.

Such examples as these prove the impact of engineering research when access between science and industry is successfully facilitated, bridging that gap that often exists and can be difficult to cross.

By understanding the architecture of the collagen fibrils, engineers and scientists can explore any structure-function relationships and work closely with an industry partner to optimise the final product.

Contributor: *Professor Richard Haverkamp, Massey University, New Zealand*

Advanced materials for energy harvesting and regenerative medicine

What is the challenge?

Advances in biomedicine, bioengineering, wearable sensor technology, packaging and myriad other applications are reliant on understanding the behaviour and characteristics of biological cells and novel materials, both as separate entities, and at their interface.

The use of computing, smart wearable devices, sensors on packaging and in our natural environment are expected to continue to increase drastically. While each of these devices is small, together, they form a substantial recycling challenge. Using the intrinsic properties of biological materials to create electronic devices that degrade naturally would represent a significant milestone in medical technology.

Biological materials are self-assembled, from sustainable resources, before being seamlessly disassembled into the biosphere at the end of their life. Importantly, biomolecules also exhibit non-classical functions, such as being inherently piezoelectric and capable of charge storage capacity.

How do chemical engineers contribute?

A research group from the University of Auckland, led by Dr Jenny Malmström, looks to nature for inspiration to develop functional materials for biological applications.

The team's research is motivated by the need for regenerative medicine to provide quality of life for our ageing population. Humans have a remarkable ability to heal and renew tissues. To achieve this, a multitude of stimuli act on cells *in vivo*, to steer their survival, proliferation, migration and differentiation. The use of stem cells presents unprecedented potential.

However, the success of such therapies is hampered by the gap in knowledge of cell fate and a lack of knowledge of stem cell behaviour *in vitro*. Although individual signalling pathways in cells are often well understood, synergistic effects leading, for example, down a particular differentiation pathway are less so. Dr Malmström and her team are developing engineered interfaces to study specific details of these important biological systems. Such fundamental understanding is needed to create surfaces able to stringently control cellular fate. Hydrogels are one such interface that facilitate the control of mechanical properties across space and time.

These gels can encapsulate cells to create *in vitro* models of tissue scars, for example cardiac scars, enabling a better understanding of scarred cardiac tissue function and innervation, and to evaluate novel treatments *in vitro*. Heart scarring is a common complication of ischemic heart disease (IHD), the leading cause of death in Australasia and worldwide.

What is the impact?

A better understanding of stem cell behaviour will lead to an increased and safer use of stem cells in tissue engineering and the treatment of degenerative diseases. Moreover, advancing the knowledge of stem cells, their behaviour, function and application makes a valuable contribution to the moral and ethical debate surrounding stem cells, and therefore social acceptance of their use in medicine.

The use of stem cells presents unprecedented potential, but the success of such therapies is hampered by the gap in knowledge of cell fate and a lack of knowledge of stem cell behaviour *in vitro.*

Contributor: Dr Jenny Malmström, University of Auckland, New Zealand

Bullet resistant materials

What is the challenge?

In a perfect world, we could reduce the number of bullet and stab wounds by simply removing weapons from the crime equation. And indeed, such legislation proved very successful in Australia following the Port Arthur massacre. However, even with strict gun ownership policies in place, Australia still records over 200 gun-related deaths per year.

In New Zealand, 4542 firearm-related offences occurred in 2020, almost doubling in the decade 2010-2020, and in the USA, nearly 40000 people lost their lives to gunshot wounds in 2019 alone.

Guns kill and it is often police who are on the front line.

For police in southern Auckland, gun violence is a daily reality, giving officers little choice but to always wear heavy vests when on duty. Bullet resistant materials save lives, yet the anti-ballistic, anti-stabbing armour is heavy and cumbersome, resulting in enduring back pain.

How do chemical engineers contribute?

Research from the University of Canterbury in New Zealand has a clear aim: to increase the odds of police officers going home to their families at the end of their shift.

To achieve this, Dr Matthew Cowan and colleagues are developing ultra-light weight bullet- and stab-resistant materials that are breathable, flexible, and can be moulded to shape.

The challenge for the researchers is to maintain the strength and flexibility of a material while reducing its weight.

The materials are tested for stab and bullet resistance in carefully controlled spike impact testing and shooting tests to ensure performance compliant with the benchmark U.S. National Institute of Justice and U.K Home Office standards.

Experimental techniques such as Scanning Electron Microscopy are used to verify the material structure and achieve quality control over repeat samples.

The team successfully developed novel composites that have about half the weight of materials with comparable protection levels (for example, a stab proof material with a weight equivalent to 10 pieces of A4 paper).

What is the impact?

Feeling safe and conformable at work is something most take for granted. The successful commercialisation of this research will relieve some of the physical, mental, and emotional load carried by police every day.

This research is being commercialised thanks to funding from the MacDiarmid Institute.

Research from the University of Canterbury in New Zealand has a clear aim: to increase the odds of police officers going home to their families at the end of their shift.

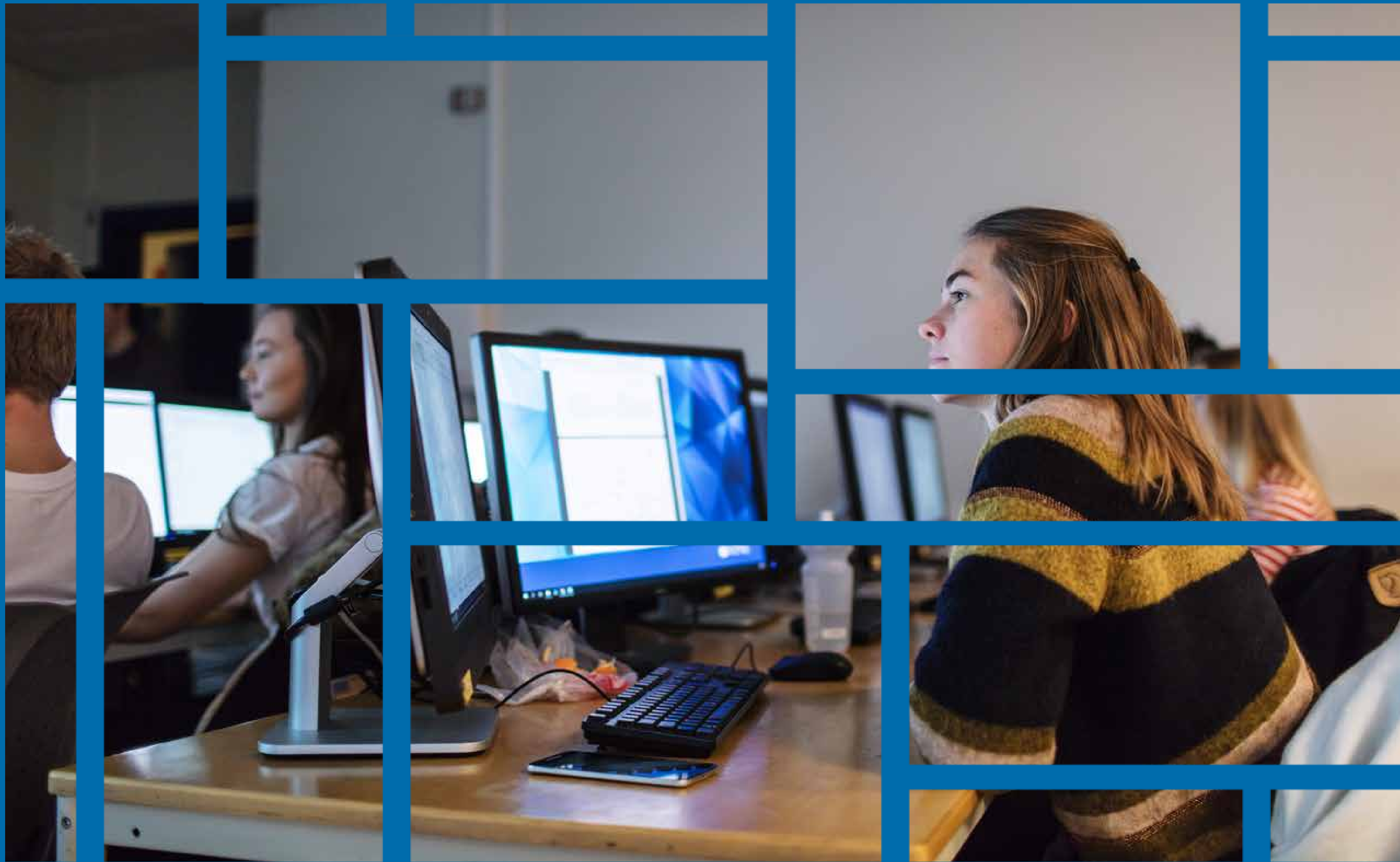
Contributor: Dr Matthew Cowan, University of Canterbury, New Zealand

Education

The world's first chemical engineering course was delivered over 100 years ago, and naturally a lot has changed since then.

The nature of the content has evolved with the technological challenges of the day, as have the modes of delivery.

Presented here are two case studies examining the impact of sudden remote learning on both students and staff, and a project designed to introduce academics to the principles of student-centred course design.



University learning in the time of COVID-19

What is the challenge?

In 2020, as the pandemic unfolded around the world, 'pivot' became the word *de jour*. For the university sector, this required a rapid transition from traditional face-to-face to online learning, leaving teaching staff to quickly rethink how to deliver quality education in an online environment. In the Faculty of Engineering at Monash University, teaching staff implemented a range of innovative changes in order translate face-to-face, hands-on and collaborative learning into a fully-online mode of delivery.

The *Teaching and Learning During COVID-19* Research project was established to better understand staff and students' experiences of the rapid transition to online learning. It sought to analyse the impact these changes had on both staff and students, capture teaching and learning changes and innovations, and provide recommendations about the most effective pedagogical approaches for online learning.

How do chemical engineers contribute?

In a comprehensive study to quickly asses the effectiveness of online learning, Associate Professor Nicoleta Maynard and her colleagues at Monash University undertook extensive staff and student surveys to capture the experiences of both sides of the university community.

Over one thousand students completed the survey from Monash University's Melbourne, Malaysia and Suzhou campuses and 183 staff from Melbourne and Malaysia campuses. In a second phase of the project, researchers interviewed 19 staff members to develop a richer understanding of the challenges, pressures and successes of the transition.

In a relatively short period of time, the team identified the range of learning pedagogies and technologies used for the delivery of fully online engineering courses, as well as the effectiveness of online learning compared with that of face-to-face instruction.

A further element of the project was to investigate the barriers and enablers in adopting educational technology, the practices of staff and students associated with more effective online learning, and the conditions influencing the effectiveness of online learning.

What is the impact?

Unsurprisingly, the rapid pivot to online teaching had measurable impact on both staff and students. Research into understanding this is important and necessary to the continuing progress for universities and their students. The lessons learnt and the feedback obtained provides all tertiary institutions a framework for meeting these challenges.

The results of this study revealed that (i) support and engagement (i.e. staff empathy, helpdesks and regular peer communication) was the overwhelmingly most important factor in supporting both staff and students during their transition to online learning; (ii) active synchronous workshops were very effective at promoting student engagement and collaboration, and (iii) students valued staff who provided honest and regular communication about the changes being made during the semester.

From a staff perspective, the rapid transition has built teaching confidence and reduced some barriers to pedagogical innovation, however without proper support it can negatively impact staff wellbeing, many of whom found themselves with a massive increase in workload and intense time pressures, among many other challenges.

The project has a number of key findings and highlighted that human connection is vital. Importantly, the study revealed that human connection can be best achieved through active online learning (case studies, problem-based activities and debates).

Contributor: *Associate Professor Nicoleta Maynard, Monash University, Australia*

The results of this study revealed that support and engagement, including staff empathy, helpdesks and regular peer communication, was the most important factor in supporting both staff and students during the transition online learning.

A student-centric education approach to course design

What is the challenge?

The pathway to academia – from PhD to postdoctoral fellowships – generally involves a lot of research and very little teaching. However, most academics are required to teach, and the public often views universities primarily as educational institutions.

Universities are increasingly prioritising student experience and student outcomes, but academics are still rarely given training about how to teach, design a course or engage students in significant learning experiences. Many people's experience is that they are handed a textbook or a slide deck and left to their own devices to figure out what to do.

New university teachers are unlikely to be aware that there is a huge body of educational research and evidence-based practices in teaching that can be drawn upon.

How do chemical engineers contribute?

The University of New South Wales (UNSW) introduced the Course Design Institute (CDI –adapted from JMUDesign, which is offered at James Madison University in Virginia, USA) in 2018, a new initiative that introduces academics to the principles of student-centred course design in a five-day course. The evidenced-based program provides ample opportunity for participants to work on their own course to make improvements.

Working in small groups under the guidance of peer facilitators, and as a large group led by Institute facilitators, the participants are exposed to fundamental concepts of course design, student motivation and assessment, as well as novel methodologies and approaches that they could implement in their own courses as appropriate. At the end of the week each participant showcases their work, which usually entails a fully redesigned module, complete with learning outcomes, activities and assessments.

Between December 2018 and April 2021, a total of 85 UNSW academics completed the course, 18 of whom are academics in the School of Chemical Engineering. Half of all the peer facilitators have been chemical engineers.

What is the impact?

Data from the 2018 cohort (before COVID-19 meant that learning moved online) showed, on average, a nine point increase in overall student satisfaction scores in 2019. For courses that had a starting score below 80, the average improvement was 24 points.

Feedback from course participants highlighted the benefit of a dedicated time within their busy schedules to focus on some professional development based around teaching. Also valuable was the connections with other academics and getting new ideas by talking to colleagues from different disciplines. Importantly, many participants reported a shift in perspective to look at the course through the students' eyes, rather than from the point of view of the teacher.

In their words: Several academics share the experience of the CDI

POSTCARD FROM CDI – CHEMICAL ENGINEERING EDITION

In April 2021, the Course Design Institute ran with 13 participants – seven of whom were from Chemical Engineering. Here, the School's participants, facilitators and education leadership talk about their experience of the CDI.

Head of School Professor Guangzhao Mao: As universal engineers, chemical engineers have long had a culture of continually learning new skills to tackle problems in new domains: this principle applies to education too and we encourage professional development to learn new approaches and polish our skills.

Dr Francisco Trujillo: The most important takeaway was the concept of backward design, in which the focus shifts toward the learning of the students, and the importance of alignment between learning outcomes and assessments.

Dr Sarah Grundy: I call it the "zero to hero" workshop in course design. It's relevant for anyone (at any level) who is involved in teaching and learning activities and want to improve their course. At the end of CDI you will have a framework for course design that you can refer back to for any course that you will be responsible for in the future.

Associate Professor Alice Lee: I saw how other teachers approached their teaching with different philosophical perspectives and methods that incorporate human elements with compassion. That inspired me.

Associate Professor Stuart Prescott: The School wants to back these efforts and help our staff turn their ideas into real changes in our courses. Keeping the momentum post-CDI is important and so we're running a round of Teaching Microgrants to provide funding that will help our staff deliver their plans.

YouTube: In their words: Several academics share the experience of the CDI (2018)

Energy

Chemical engineers have always been close to the provision of energy, from extraction, refining and distribution of fossil fuels through to the innovation and development of new cleaner and sustainable energy sources.

Chemical engineering research into energy ranges from hydrogen conversion and storage, to supercapacitors and biofuels.

Presented here are three examples of research from across Australia and New Zealand working toward delivering clean, sustainable and affordable energy for a carbon neutral future.

Faking photosynthesis to tackle climate change

What is the challenge?

The relationship between anthropogenic carbon emissions and climate change, and the devastating consequences are all too well documented. With Australia consistently recording one of the highest annual emissions per capita of all developed countries, with much of it coming from the power industry, there is a significant need to pivot the *status quo* approach to energy generation, storage and use.

How do chemical engineers contribute?

The Particles and Catalysis (PartCat) Research Group at the University of New South Wales, led by Scientia Professor Rose Amal AC, has focussed on novel technologies for renewable energy applications for a number of years.

More recently the group has dedicated its expertise to closing the carbon loop, or more specifically converting carbon dioxide into useful products and fuels, as well as generating carbon-free sources of energy carriers such as hydrogen and renewable ammonia. Importantly, the group also carries out techno-economic feasibility of these technologies within both domestic and export markets, recently focusing on export opportunities to Germany and Asia-Pacific.

Research into the conversion of carbon dioxide into useful products and fuels includes using electrocatalysis to convert carbon dioxide into a range of key products, for example, synthesis gas (syngas - hydrogen and carbon monoxide), formic acid, and higher alcohols. As source materials, they target those which are cheap, abundant and available in Australia, while also studying the impact of contaminants potentially present in waste carbon dioxide streams.

Group members Dr Emma Lovell and Dr Rahman Daiyan have detailed a way of creating nanoparticles that promote conversion of waste carbon dioxide into useful industrial components. For example, they have successfully applied flame spray pyrolysis (FSP) to produce nanoparticles of zinc oxide that then act as a catalyst to turn CO_2 into syngas used in the manufacture of many industrial products including synthetic diesel, methanol, alcohol or plastics.

In a second carbon conversion project, the PartCat team have examined the thermal conversion of carbon dioxide into fuels such as methane. Carbon dioxide is a very stable molecule so typically temperatures above 400 °C are required for conversion into methane. By offsetting this thermal energy requirement using sunlight, specifically by capturing visible light and near infrared light to drive the reaction through additional heat, as well as plasmonic generated hot electrons, this technology reduces the carbon footprint considerably.

A stand out example of carbon free sources of energy is the generation of green ammonia. Ammonia is being increasingly examined as a key potential vector for hydrogen in the emerging hydrogen economy (especially considering ammonia stores more hydrogen per litre than liquid hydrogen). One of the limitations is the current approach to making ammonia, which has a big carbon footprint and requires large scale production. Scientia Professor Amal and the team have recently developed an approach to make ammonia using only air, water and renewable energy. As part of this research they have also developed an approach to convert waste NOx (from industry and potentially from ammonia combustion in a future hydrogen economy) into ammonia using renewable energy, enabling a circular economy.

What is the impact?

The renewable ammonia technology has resulted in three patent applications and industry collaboration to commercialise the technology.

The group's CO_2 reduction technologies (including others) form the basis of a powerfuel network we created in New South Wales, bringing together 50 companies and universities.

With Australia consistently recording one of the highest annual emissions per capita of all developed countries, with much of it coming from the power industry, there is a significant need to pivot the *status quo* approach to energy generation, storage and use.

Contributors: Dr Emma Lovell, Dr Rahman Daiyan, Scientia Professor Rose Amal AC, University of New South Wales, Australia

Recycling and managing waste from electric vehicle (EV) batteries

What is the challenge?

The New Zealand Climate Change Commission recommended that battery-powered vehicles be widely adopted, and in June 2021 the New Zealand government announced the ban of importing fossil fuel-powered vehicles from 2030.

Each imported EV equates to the import of a significant number of large battery packs. For example, Tesla S Model's 90 kWh battery weighs 540 kg. Although the benefit of adopting EVs is obvious (arguably zero-carbon emission), another big issue, often overlooked or neglected, is how do we manage the vast amount of spent batteries. Without an effective strategy to deal with these batteries, we risk another waste headache, akin to plastics and tyres. Currently, many of the developed battery recycling technologies are not economically viable, nor are they environmentally benign. Instead, many of them are energy intensive and produce secondary pollution.

How do chemical engineers contribute?

Associate Professor Peng Cao leads a research group to develop high-performance energy-storage materials and devices, focusing on solid-state electrolytes, high-capacity anodes and supercapacitors. His group is also developing recycling/upcycling technologies for lithium-ion batteries and are working on two strategies: (1) direct regeneration of the degraded cathodes so that they can be directly used in battery assembly and (2) a metal extraction process that uses a green solvent.

The team's research is focussed on two aspects associated with EV battery recycling.

Firstly, to regenerate the degraded cathode (the positive electrode in battery). A properly regenerated cathode has equal performance output as a pristine electrode and can be directly re-inserted during battery manufacture. This minimises the use of the battery raw materials, and the associated mining.

The method developed in Dr Cao's laboratory uses only environmentally benign solvents and produces no secondary pollution.

In a second research project, the team is investigating how to deal with the battery cells that cannot be re-used or electrodes regenerated. For the non-usable battery cells, the objective is to extract all metals and thus leave no hazardous substances in the landfill. Again, the process for metal recovery/extraction uses only green solvents with no secondary pollution. The developed Levulunic acid-based deep eutectic solvents have demonstrated high extraction efficiency for lithium (Li), cobalt (Co) and nickel (Ni).

Current research is focussed in improving efficiency and therefore economic viability.

Contributor: Associate Professor Peng Cao, The University of Auckland, New Zealand

What is the impact?

Although in the foreseeable near future, the quantity of retired/non-usable EV battery cells will be relatively small, New Zealand authorities are committed to a proactive approach. A Battery Industry Group (B.I.G.) has been established with the support of the New Zealand Ministry for the Environment (MfE), Energy Efficiency and Conservation Authority (EECA), the Motor Industry Association and Vector.

In May 2021, B.I.G. submitted a proposed product stewardship scheme for large batteries to the MfE to initiate government level regulation for EV batteries.

The team is currently working with local industry collaborators including e-waste recyclers, waste management companies and various research organisations to further develop their EV battery recycling technologies.

The benefit of adopting EVs is obvious. However, how will we manage the vast amount of spent batteries and avoid another waste headache, akin to plastics and tyres.

Renewable hydrogen from methane using the Hazer process

What is the challenge?

As Australia and the global community rush to develop clean energy and end our reliance on fossil fuels, hydrogen, especially blue, turquoise and green hydrogen, is a hopeful contender for the conveyance of clean energy to end users. The modes of conveyance include blending into existing gas pipelines, transportation and maritime exportation via compression or liquefaction.

Blue, turquoise and green hydrogen could play a key role in the energy transition, but challenges, including cost as well as power grid and supply chain constraints currently hinder commercial viability.

How do chemical engineers contribute?

This story started when Professor Chua was transitioning from the National University of Singapore to The University of Western Australia in 2004. He realised then that Western Australia was rich in natural gas, and was keen to transform it into near zero-emission hydrogen. He led the initial research to develop hydrogen by breaking the chemical bond of naturally occurring gas methane.

In 2010, the technology was commercialised into the spin off company *Hazer*. The Hazer Process converts methane rich gas into hydrogen and sequesters the carbon as graphitic carbon via an iron oxide catalyst. The purified carbon samples were also sent to Institute of Chemical and Engineering Sciences in Singapore to be independently evaluated for battery applications.

More recently, a new State Government project to produce renewable hydrogen and graphite from wastewater will use this technology. The project is an Australian-first and expected to produce around 100 tonnes of fuel-grade hydrogen and 380 tonnes of graphite each year, with the potential for expansion.

The technology capitalises on the waste product of biogas. The biogas, primarily composed of methane and carbon dioxide, is released during the wastewater treatment process as solid matter (biosolids) breaks down. While most of this renewable fuel is currently used to produce electricity for the treatment plant, the excess is usually burned off. However, thanks to this novel technology, it will be converted into valuable materials using an iron ore catalyst to produce low-emission hydrogen and graphite.

What is the impact?

Hazer was spun off from UWA in 2010 and was public listed in 2015 (ASX:HZR). The present market capital of Hazer is AUD$200 M. The Hazer Group is a member of the Australian Hydrogen Council, which is the peak body for the hydrogen industry.

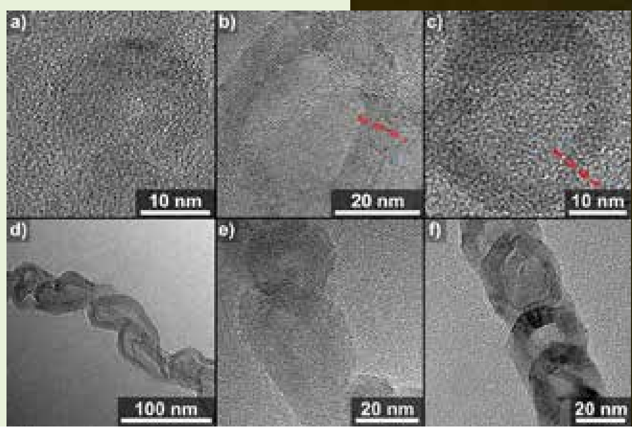
In June 2020, Hazer partnered with Water Corporation to convert bio-gas into hydrogen and graphitic carbon. This project was also supported by Australian Renewable Energy Agency (ARENA)..

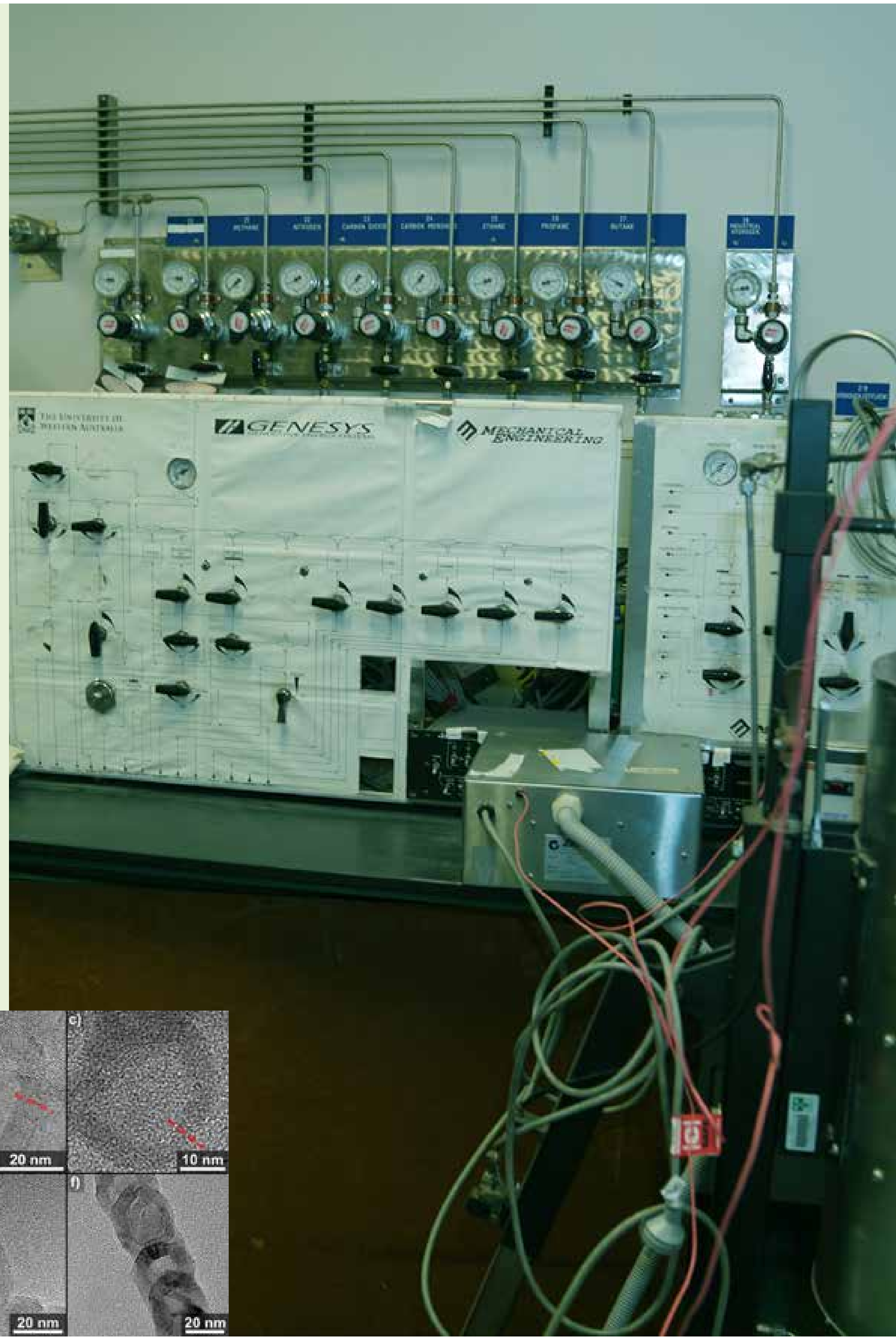
The project will support the State Government's Renewable Hydrogen Strategy to foster growth in the WA hydrogen industry.

The Hazer Process has garnered four granted patents and 28 pending patent applications covering three separate inventions.

Both turquoise and green hydrogen could both play a key role in the energy transition, but challenges, including cost as well as power grid and supply chain constraints currently hinder commercial viability.

Purified carbon (below), Hazer lab (right)





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