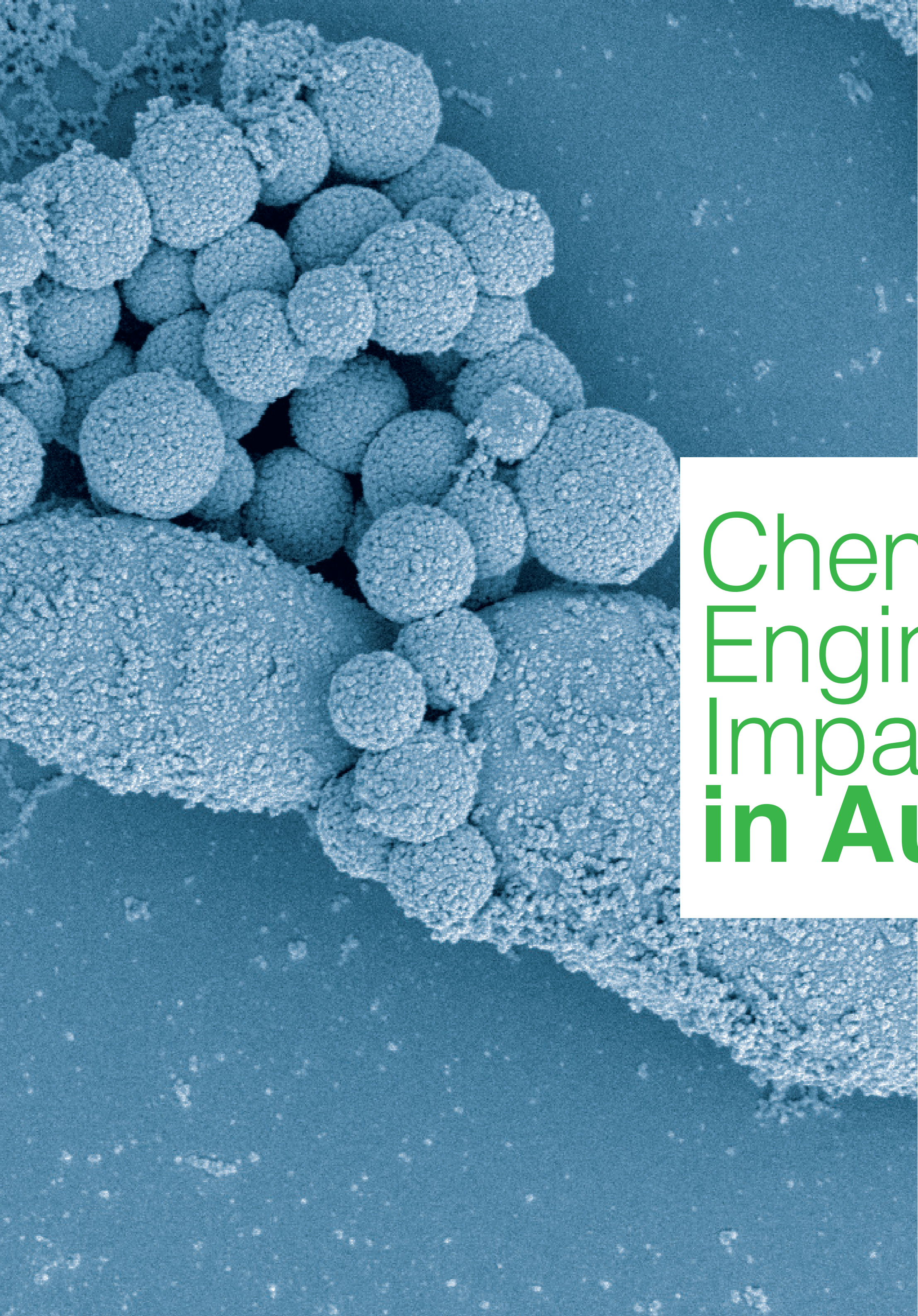


# Chemical Engineering Impact **in Australia**

IChemE

ADVANCING CHEMICAL ENGINEERING WORLDWIDE

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 around 37,000 members in over 100 countries who are supported by a team of professional staff based in Australia, Malaysia, New Zealand, Singapore and the UK.

Australia represents 10% 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 its positive impact on the way we live.

# foreword

We research engineers are often asked about what we do, why we do it, and whether it is *really* making a difference. Chemical engineering especially was frequently misunderstood as dirty and dangerous, creating noxious waste products.

As researchers investigating the world at the interface between science and engineering, we have a duty – at a time when expert opinion is often challenged and sometimes rejected – to communicate what we do to the broader community.

In this context in particular it makes me very proud to present this collection of case studies showcasing our answers to some of Australia's priority challenges in energy, water, environment and health.

This collection highlights the breadth and depth of chemical engineering, and demonstrates how our discipline is making real change for a better future for Australia. We hope it may also be a resource that can contribute to the public understanding of what we do to achieve an equitable and sustainable future.

Each case study provides context to the challenge being addressed, outlines how chemical engineers contribute and the impact of this work in regard to social, economic and environmental outcomes.

As a collection the case studies also illustrate the level of cross disciplinary cooperation that our researchers pursue in order to achieve the best and most practical outcomes for the end users.

In selecting the case studies for inclusion in this booklet we have sought to illustrate the broad array of activities across the nation, from water desalination technologies, insights into sports injuries, innovations in solar energy and waste management.

We have a long history of chemical engineering in Australia, and we hope this publication delivers in its objective to highlight these wonderful research outcomes, and contributes to the improved public understanding of our discipline.

I would like to take this opportunity to thank Professor Cordelia Selomulya (Monash University/UNSW) and Australia IChemE Research Committee member Mr Peter Slane for driving this project, and to IChemE in Australia Research Committee member for supporting the initiative. I would also like to thank all the researchers who contributed to this publication, helping us to promote the role of chemical engineering in a sustainable Australia.

Professor Rose Amal AC FIChemE
Former Chair, IChemE in Australia

# contents

# energy

SOLAR CELLS AND QUANTUM DOTS

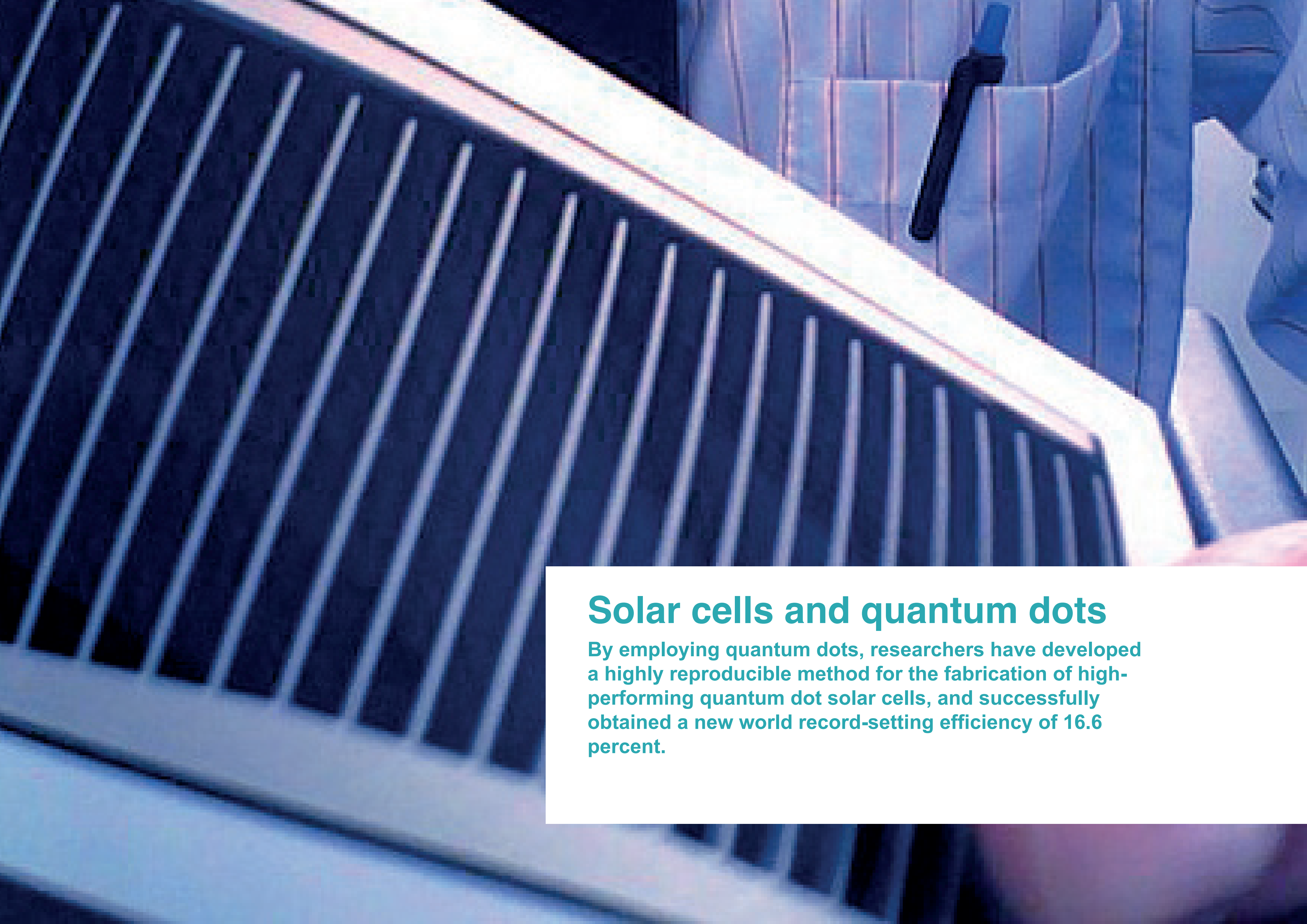
ALLEVIATING ENERGY POVERTY

MEMBRANES FOR CARBON CAPTURE

**When chemical engineers focus on improving the long term sustainability and equitability of energy, they combine fundamental scientific research with applied technologies to create novel and feasible solutions.**

**Across Australia, research groups are working on diverse topics including hydrogen fuel technologies, photovoltaic materials, clean coal technologies, biofuels, advanced membranes and novel materials.**

**The sustainable acquisition, processing, and use of energy represents a major global challenge and is a priority of chemical engineering research in Australia.**



# Solar cells and quantum dots

**By employing quantum dots, researchers have developed a highly reproducible method for the fabrication of high-performing quantum dot solar cells, and successfully obtained a new world record-setting efficiency of 16.6 percent.**

# Colloidal quantum dots for next-generation photovoltaic technology and beyond

## What is the challenge?

Solar energy stands out as one of the most viable and environmentally sustainable solutions to ensure Australia's ongoing energy security. Large-scale solar electricity is rapidly expanding in the world; more than two million Australian households have installed rooftop solar systems, and in 2020 a 250-megawatt solar power plant will be built in India. Globally, cumulative photovoltaic installations reached 500-gigawatts at the end of 2018, however the market is still dominated by costly crystalline silicon (c-Si) solar cells.

Solar cells have potential uses other than grid-scale electricity producers. Decentralised, flexible, and lightweight solar cells have exciting applications in portable and wearable electronics, integrated photovoltaic windows used in buildings and automobiles, and use in aircrafts. Yet the current c-Si wafer-based solar cells cannot be employed in these applications as they are brittle, thick, and require high temperatures for processing. Highly flexible and lightweight power generators are needed to address future energy challenges.

## How do chemical engineers contribute?

Research at the School of Chemical Engineering and the Australian Institute of Bioengineering and Nanotechnology (UQ), led by Professor Lianzhou Wang, has focussed on the development of a new class of semiconductor materials that have solution-processability at low temperatures, chemical and mechanical stability at ambient environment, and excellent optoelectronic properties. These are all favourable characteristics for the fabrication of low-cost, stable, flexible devices with improved solar energy conversion efficiency.

Colloidal quantum dots (QDs) are a promising material in numerous photonic technologies, including solar cells, light emitting diodes (LEDs), lasers, radiation detectors and photodetectors. Such QDs are especially advantageous due to the tunability of the material bandgap, energetic position of the electronic states and surface chemistry. Furthermore they can be synthesised at low temperature and be applied to solar printable technologies.

High power efficiencies have been reported in solar cell devices with quantum dots. The UQ researchers had a recent breakthrough in the low-cost next generation quantum dot solar cells (QDSCs) that achieved a world record steady-state power conversion efficiency of 16.6 percent, which is over three percent higher than the previous record efficiency.

## What is the impact?

This new-generation of colloidal QDs feature excellent optoelectric properties, which offer the promise of low-cost, large scale photovoltaics and high efficiency beyond the Shockley-Queisser limit (~30 percent) of conventional PV materials. In addition, the robust mechanical strength, due to the strong interparticulate interactions, make QDs promising candidates among all the emerging PV materials for lightweight and flexible solar cells.

Further to PV application, the QDs developed at UQ also hold great potential in light emitting diodes (LEDs), which are a highly promising new generation display technology beyond Organic LED-displays with pure colour position, high luminance and lower power consumption. The introduction of QDs into LED design also marks a critical step forward in reducing the cost of LED production and making them more affordable for the average consumer.

With the assistance of UniQuest as the commercialisation facilitator, a number of companies including Nanosys, Quantum Materials Corp, NanoPhotonica, and LG have expressed their interest in this new technology.

***This technology has the potential to sustainably develop a new class of semiconductor materials with excellent optoelectronic properties for the fabrication of low-cost, stable, flexible devices with improved solar energy conversion efficiency.***

*Contributors:*
*Professor Lianzhou Wang & Dr Yang Bai*
*(University of Queensland)*

## Alleviating energy poverty

**The Energy and Poverty Research Group (EPRG) is leading research that transcends research disciplines, governments and industry partners. Transformation experts aim to drive behavioural change that will inform solutions to alleviate energy poverty across the globe. This vision is in line with the United Nations' goal to provide universal access to modern and reliable energy services by 2030.**

# energy

## Bringing reliable and modern energy solutions to the developing world

### What is the challenge?

Almost three billion people in developing regions live without reliable, modern energy services. While access to electricity is increasing, large sections of the global population continue to use unclean, solid fuels such as wood, charcoal and agricultural and animal waste for daily cooking and heating. The social, economic and environmental impacts associated with energy poverty are well-documented. For example, the World Health Organisation estimates over three million people die prematurely due to indoor air pollution. Or the deforestation and irreversible environmental degradation resulting from the collection and transport of cooking fuel, with disproportionate impacts on women and girls.

The challenge is to provide affordable, modern, clean and efficient energy services that contribute to enhanced social and economic development for people and communities globally. Addressing this challenge is one of 17 Sustainable Development Goals identified by the United Nations (Goal 7), which calls for making clean, reliable and affordable energy available for all by 2030.

### How do chemical engineers contribute?

EPRG and The University of Queensland (UQ) focusses on changing the cultural mindset of using traditional energy sources, and seeking affordable solutions that will provide reliable energy. EPRG's chemical engineering experts work with researchers skilled in social sciences, psychology, business, public policy, communications and mechanical engineering to recognise, and address, the complex challenge of energy poverty.

The group mostly works in India and the South Pacific. One such project is in the village of Nakkalavarikota in the southern Indian state of Andhra Pradesh, where roughly 200 people live in extreme poverty. They use grid-based electricity access for use of televisions, radios and mobile phones, but continue to rely on firewood for heating and cooking purposes. Encouraging change is challenging. Broadly, this research project seeks to understand why some families are reluctant to abandon their traditional cooking fuels, and, in the process, unpack the underpinning social and behavioural constructs that drive their resistance towards a cleaner energy transition.

Members of the EPRG are also exploring other issues important to understanding and overcoming energy poverty, such as the role of the private sector in rural electrification; the value of energy access in building greater resilience to disaster events; the positioning of, and myths about, gender in the energy access discourse, designing and delivering energy literacy programs; and harnessing local resources such as municipal solid waste to make an economic and environmental case for alternative liquid cooking fuels.

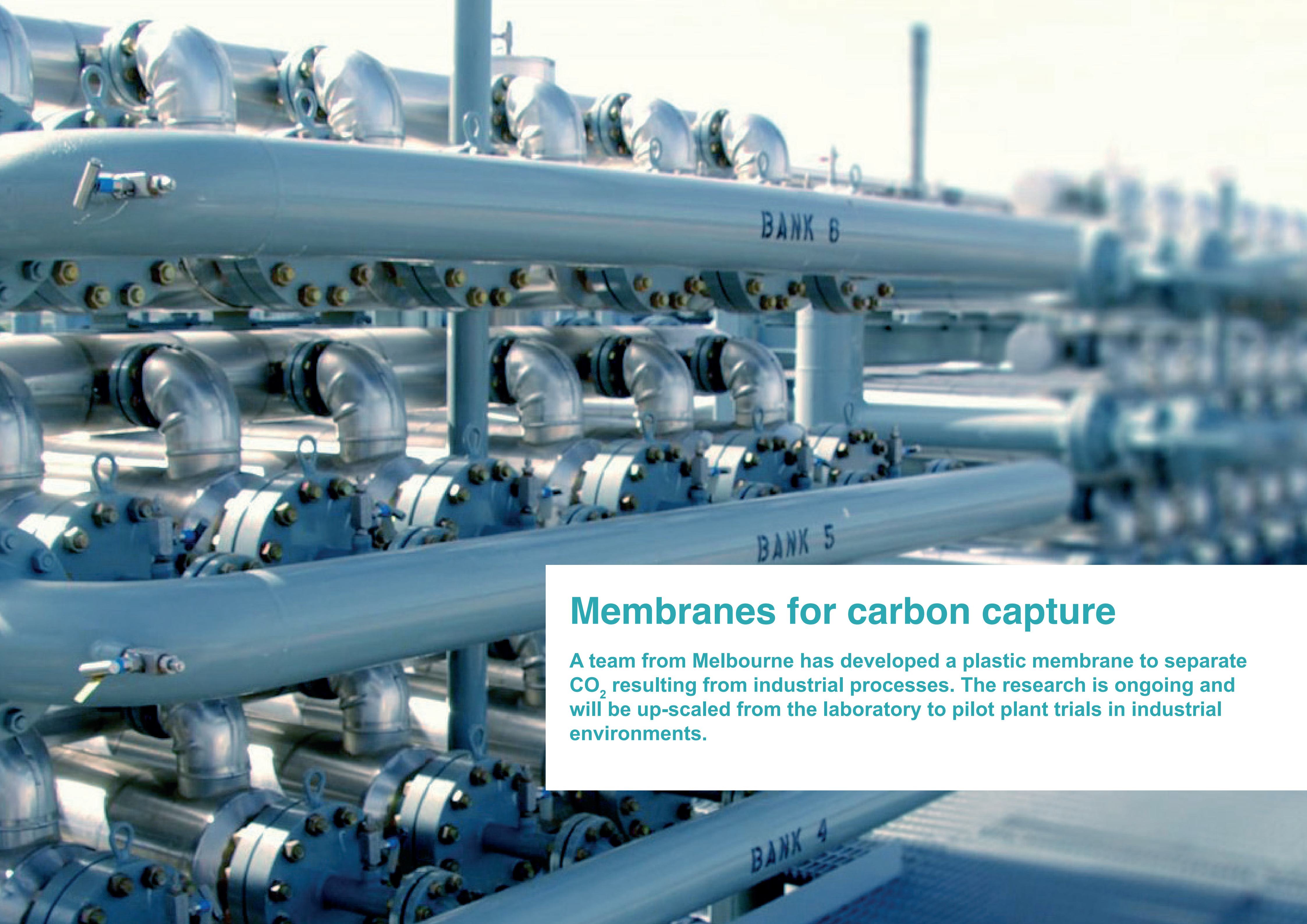
### What is the impact?

To date, the EPRG has established strong foundational research, and identified profound social and cultural insights. The unique collaborative and multidisciplinary research approaches have built a solid network of collaborators comprising academic, policy (think tanks) and private sector organisations across India, Nepal, Cambodia, Myanmar, South Africa, Solomon Islands and Papua New Guinea. Through its array of PhD projects, the EPRG continues to work with in-country partners to co-design and co-develop innovative, low-cost and scalable solutions that meet locally driven and contextually-relevant energy access needs.

Moving forward, the EPRG plans on further partnering with governments and the private sector to maximise impact and expand work to other world regions challenged by energy poverty.

***The work will be expanded to the Pacific and South-East Asia. The findings from India provide an insight across all scales, from small villages to project mapping of over 160 countries.***

*Contributors:*
*Professor Paul Lant & Dr Vigya Sharma*
*(University of Queensland)*




# Membranes for carbon capture

**A team from Melbourne has developed a plastic membrane to separate $CO_2$ resulting from industrial processes. The research is ongoing and will be up-scaled from the laboratory to pilot plant trials in industrial environments.**

# Membranes for carbon capture

## What is the challenge?

All widely used modern chemical products need to be purified from their original form using chemical separation technology, which involves very energy intensive processes. Currently, conventional separation technology is responsible for 10 to 15% of the world's energy consumption, and thus the primary source of atmospheric carbon dioxide.

It is therefore imperative that we develop cheap, easy and efficient methods of filtering carbon dioxide from these industrial exhaust gases. Current methods for carbon dioxide removal include stripping, adsorption and reversible solvent absorption. These methods are tedious and expensive.

In contrast, plastic membranes are cost effective and convenient, and represent a sustainable approach to reduce the energy demand of chemical separation and ensure a cleaner future.

## How do chemical engineers contribute?

Dr Colin Scholes and his team from the University of Melbourne have developed a membrane made of plastic, which can separate carbon dioxide from flue gas and can be fitted to existing chimneys for carbon capture and storage.

These membranes are based on materials that create a selective barrier that enables certain chemicals to transverse, while preventing others. This is achieved through a number of processes, including the chemical affinity certain chemicals have for the membrane material, size exclusion, and as electrostatic attraction/repulsion between chemicals and the membrane. The key is that the separation is achieved through a chemical potential across the membrane, and therefore avoids the need for high energy processes.

The team are currently developing membranes that can selectively separate out carbon dioxide, hydrogen, methanol, ammonia and syngas components; this enables the cost-effective and efficient chemical processing of industrial gases, natural gases and future fuels.

The membranes were prepared using a polymer material that resembles a plastic film. On passing a stream of industrial exhaust gas through the membrane, they observed that carbon dioxide passed through, but oxygen and nitrogen did not. Researchers are examining this technique in brown coal power stations in Victoria's La Trobe valley in Australia, hoping to achieve a reduction of carbon dioxide emissions of up to 90%.

## What is the impact?

Membrane research is ongoing at all stages of the commercialisation pathway; from the development of novel materials, the testing of these materials under various conditions in the laboratory, simulation of membrane processes, as well as pilot plant trials in industrial environments.

Further research will improve the efficiency of carbon capture using plastic films and to explore the applicability of the films in aqueous media. In addition to testing the sheets in industrial streams of exhaust gas, researchers are trying to make them more cost-effective. Successful demonstrations would result in scaling up of this technique and implementation at an industrial scale.

Industry collaborators include major multinational energy and chemical companies, Australia's energy sector, and local chemical and processing companies.

***The membranes are being tested in brown coal power stations in Victoria's La Trobe valley, hoping to achieve $CO_2$ emission reductions of up to 90%.***

*Contributors:*
*Dr Colin Scholes & Dr Kevin Li*
*(University of Melbourne)*

# water

SOLAR ENERGY TO DESALINATE OCEAN WATER

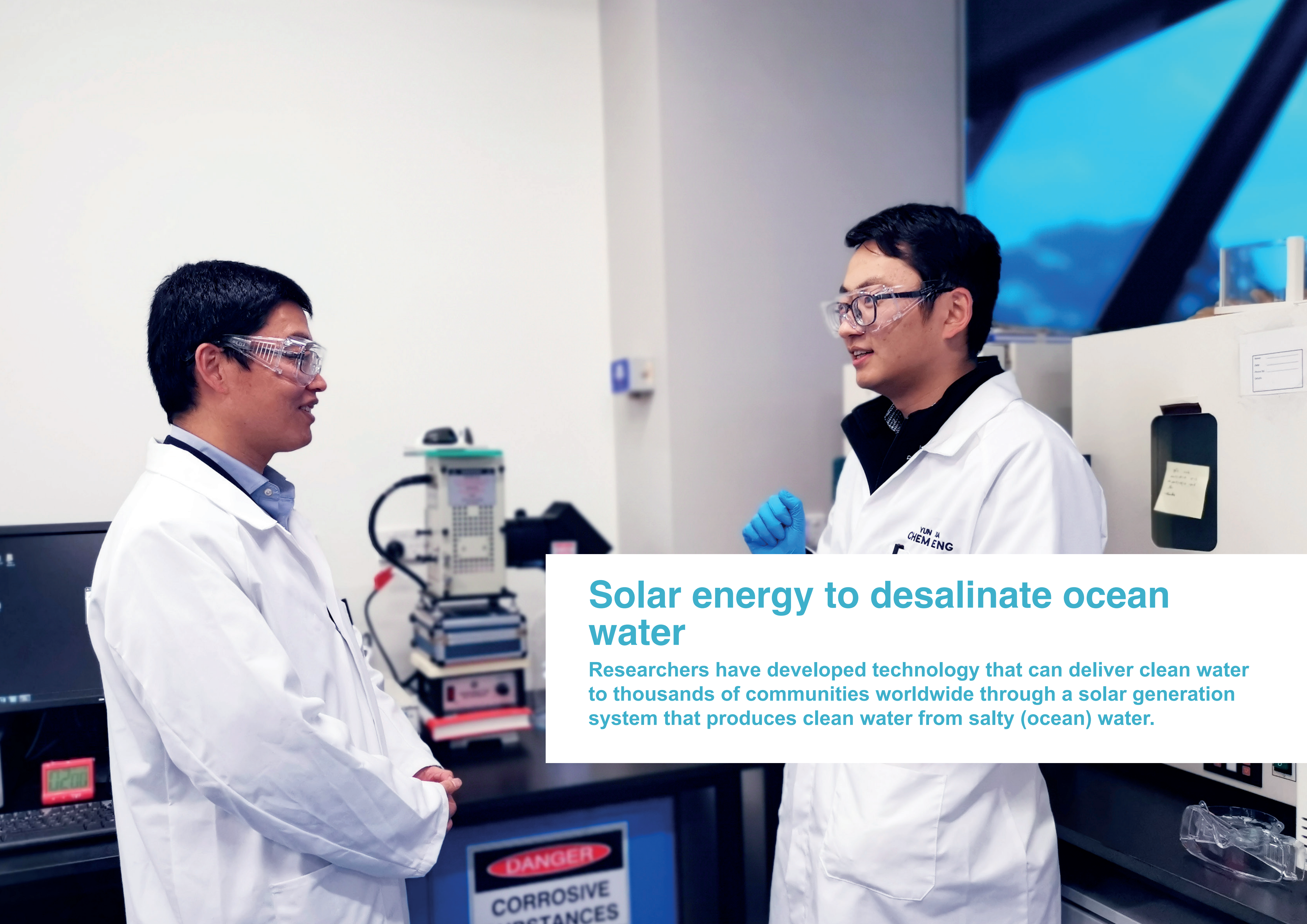
EFFICIENT AND SUSTAINABLE WATER FILTRATION

COMBATING GREENHOUSE GAS EMISSIONS FROM WASTEWATER SYSTEMS

**We have long recognised the limits of our natural resources. However, as populations rapidly increase, and rainfall events become more unpredictable, the scarcity of fresh water has been brought into sharper focus.**

**Engineering has been central to delivering clean water and managing waste water since the Romans constructed aqueducts throughout their empire.**

**Today's engineering solutions need to address urgent water supply issues in a manner that is socially, economically, and environmentally sustainable.**




# Solar energy to desalinate ocean water

**Researchers have developed technology that can deliver clean water to thousands of communities worldwide through a solar generation system that produces clean water from salty (ocean) water.**

# water

## Solar energy to desalinate ocean water

### What is the challenge?

It is estimated that 844 million people do not have access to clean water, while every minute a newborn child dies from infections caused by the lack of safe water and an unclean environment. Conventional approaches including seawater desalination and wastewater recycling have been used to ease the problem of water storage, but these approaches are energy-intensive and based on the combustion of fossil fuels; water treatment uses about three percent of the world's energy supply.

Water security is the biggest global challenge of the 21st century, especially as the population grows and the effects of climate change take shape. Developing and under-resourced communities feel the effects of these factors the most.

### How do chemical engineers contribute?

Researchers at the Department of Chemical Engineering at Monash University have developed an energy-passive technology that is able to deliver clean, potable water to thousands of communities, simply by using photothermal materials and the power of the sun.

The researchers have developed a robust solar steam generation system that achieves efficient and continuous clean water production from salt water with almost 100 percent salt removal. By precisely controlling salt crystallisation only at the edge of the evaporation disc, this novel design also can harvest the salts.

Despite the significant progress achieved in material development, the evaporation process has been impeded by the concentration of salt on the surface, which affects the quality of water produced.  To overcome this, researchers created a disc using super-hydrophilic filter paper with a layer of carbon nanotubes for light absorption. A cotton thread, with a 1 mm diameter, acted as the water transport channel, pumping saline water to the evaporation disc.

The saline water is carried up by the cotton thread from the bulk solution to the centre of the evaporation disc. The filter paper traps the pure water and pushes the remaining salt to the edges of the disc.

### How has this made an impact?

This technology brings us closer towards the practical application of solar steam generation technology, demonstrating great potential in seawater desalination and resource recovery from wastewater, with no liquid discharge.

The researchers hope this will be a starting point for further research in energy-passive ways of providing clean and safe water to millions of people, eliminating the environmental impact of waste and recovering resources from waste.

The feasibility and durability of the design have been validated using seawater from Lacepede Bay in South Australia, with a water production rate of 650ml an hour. This technology is a promising solution to water shortages in regional areas where grid electricity is not available.

***This technology has great potential in other fields, including the wastewater industry, mining tailings management and resource recovery. Future studies will look to extend the technology to these applications with industry support.***

*Contributor:*
*Professor Xiwang Zhang (Monash University)*
*(Pictured: Xiwang Zhang with student Yun Xia)*

# Efficient and sustainable water filtration

**Researchers have discovered that metal-organic frameworks (MOFs) in membranes can mimic the filtering function, or ‘ion selectivity’, of organic cell membranes. This discovery could lead to the dual functions of removing salts from water and separating metal ions in an efficient manner, offering a revolutionary new technological approach for the water and mining industries.**

# water

## Efficient and sustainable water filtration

### What is the challenge?

Globally, two billion people lack access to clean and safe drinking water. Currently, reverse osmosis membranes are responsible for more than half of the world's desalination capacity, and is the last stage of most water treatment processes, yet these membranes have room for improvement by a factor of two to three in energy consumption. Furthermore, as they do not operate on the principles of dehydration of ions, or selective ion transport in biological channels, they have significant limitations.

An example of this problem is reducing natural fluoridation levels of water in some developing communities. The World Health Organisation guidelines determine fluoride to be safe for human consumption in levels up to 1.5 mg/litre. Many developing countries have higher natural fluoridation levels in their groundwater, yet lack the energy source and cost-efficient methods to filter the water effectively.

Many industrial sectors also face filtration challenges. For example, the agricultural sector is increasingly searching for ways to clean up water pollution caused by fertiliser and pesticides, particularly in areas where contaminated run-off is at risk of entering rivers and the oceans.

### How do chemical engineers contribute?

Research at the Department of Chemical Engineering at Monash University, in conjunction with researchers at the CSIRO, The University of Melbourne and The University of Texas at Austin have established an unprecedented new method to filter contaminants from groundwater and industrial wastewater, opening up new options to provide safe, clean drinking water in the developing world, and to protect the natural environment from industrial water pollution.

The researchers have developed a control method through which to separate particular negatively-charged ions (anions) from water using Metal-Organic Frameworks (MOFs). MOFs are advanced nanostructural materials comprised of porous crystals with metal ions joined together by organic linkers. MOFs contain molecular-sized pores that can store, separate, release or protect many substances, and can be scaled up to suit a variety of industrial purposes.

The team developed a MOF with precisely tuned pores of a size and chemistry to be compatible with the selected ion. When passing over the filter material, the selected ion was attracted to the pore, and easily passed through with little force or resistance, while other ions were largely unable to pass through the pores.

### What is the impact?

The development of a MOF with precisely tuned pores of a size and chemistry to be compatible with the selected ion is an unprecedented breakthrough. As in other water filtering methods, all forms of ions need to be removed and filtered to extract the unwanted substance from the water, a costly and energy-intensive process that often requires some of the filtered ions to be added back into the water once the unwanted ions are removed.

The research team has successfully demonstrated this technique by identifying a MOF that showed high selectivity for fluoride anions over other anions. Selectively removing targeted ions from water with such high levels of specificity provides new pathways to address fundamental challenges in energy-efficient production of fit-for-purpose water for a variety of water and energy applications. This outcome is also an example of using high-tech, next-generation technologies to assist in the transition to a circular economy, where long-term management of wastes can generate new industries, while also protecting the environment.

***This research enables the production of simple and affordable water filters that can be used safely and effectively anywhere in the world. This is a significant outcome for people in developing countries who lack access to safe, clean drinking water, and for industries who are increasingly seeking ways to reduce the cost of their environmental impact.***

*Contributor:*
*Professor Huanting  Wang*
*(Monash University)*

# Combating greenhouse gas emissions from wastewater systems

**Researchers have developed a novel, real-time monitoring approach that accurately quantifies nitrous oxide ($N_2O$) emissions, resulting in the development of one of the world's most advanced $N_2O$ models. The model can be used to identify causes, and subsequently simulate operational control measures capable of reducing $N_2O$ emissions.**

## Combating greenhouse gas emissions from wastewater systems

### What is the challenge?

For many Australian water utilities, there is a regulatory requirement to reduce or achieve net zero greenhouse gas (GHG) emissions. To achieve this, water utilities are faced with the challenge of how to both quantify and reduce direct emissions released from wastewater treatment plants (WWTPs). One example is nitrous oxide ($N_20$), a by-product released during the biological nitrogen removal step (e.g. activated sludge).

With a global warming potential 310 times greater than $CO_2$, $N_2O$ can represent more than 70 percent of a WWTPs total emissions. For this reason, the ability to know a plant's true emission output is important, not just for reporting purposes, but in order to develop a baseline from which improvements can be assessed and benchmarked.

### How do chemical engineers contribute?

Research at the School of Chemical Engineering and Advanced Water Management Centre at The University of Queensland, in conjunction with South Australia Water and their commercial business unit Water Engineering Technologies, has led to the development of a novel real-time monitoring approach. Using this new method, the team accurately quantified $N_2O$ emissions from two activated sludge plants located at South Australia's largest WWTP. Through this hands-on partnership, the team gained a clear and accurate understanding of emissions, from which they developed one of the world's most advanced $N_2O$ models.

This new real-time monitoring system incorporates diurnal, spatial and temporal variations into $N_2O$ accounting. The ability to quantify diurnal and spatial variability in emissions was crucial to accurately quantify the plants overall emissions. This resolution also facilitated the identification of emission 'hotspots' along the activated sludge process, which can be used to identify process inefficiencies as well as target optimisation and control measures.

### What is the impact?

The model developed by the researchers was used to identify causes, and subsequently simulated a number of operational control measures capable of reducing $N_2O$ emissions. When one such operational improvement was implemented, it resulted in up to 40 percent reduction in emissions. Additionally, this was coupled with improvements in effluent water quality and energy efficiency. The model serves as the world's first full-scale example where the development of cutting edge $N_2O$ monitoring has enabled the implementation and validation of abatement measures.

This research was the first to characterise and document $N_2O$ emissions from a 'Step-Fed' active sludge plant, which is a common configuration used globally for nitrogen removal. Prior to this, no detailed $N_2O$ emission data from this type of process had existed. In particular, this research provided new insights into how the design and operation of the Step-Fed process impacted $N_2O$ emissions - valuable information for water utilities with regard to planning and decision making.

The work has been included in the new *Guidelines for National Greenhouse Gas Inventories* as updates in the *Wastewater Treatment and Discharge* chapter and won the 2018 South Australian Research Innovation Award as part of the Australian Water Association Water Awards.

***The outcomes from this research have been implemented by Allwater at one of their full-scale active sludge plants. Real-time $N_2O$ measurements at the Bolivar High Salinity activated sludge plant have confirmed that aeration improvements have reduced $N_2O$ emissions by up to 40 % - the equivalent to 890 tonnes of carbon dioxide per annum.***

*Contributors:*
*Professor Zhiguo Yuan, Dr Liu Ye, Dr Haoran Duan (University of Queensland)*
*Dr Ben van den Akker (SA Water)*

# nano medicine

STRETCHABLE GOLD SKIN

UNDERSTANDING ANTERIOR CRUCIATE LIGAMENT (ACL) FAILURE MECHANISMS

DEVELOPING CLINICALLY RELEVANT BIOSENSORS

**Nanomedicine is an interdisciplinary field of research at the interface of science, engineering, and medicine, with broad clinical applications ranging from molecular imaging to medical diagnostics, targeted therapy, and image-guided surgery.**

**Despite significant advances in nanomedicine, there are still major fundamental and technical barriers that need to be understood and overcome.**

**Chemical engineers help to unlock these mysteries as they investigate materials at the nanoscale.**

# Stretchable gold skin

**A team of chemical engineers from Monash University have had promising results in the development of a stretchable skin that can be used to monitor a wide variety of medical conditions. In this ground breaking study, the team could demonstrate that a staircase-like design can be extended to other configurations, such as spiral and concentric patterns.**

## Stretchable gold skin

### What is the challenge?

Human skin is remarkable. It can sense an external object in a location-specific manner, simultaneously recognising whether it is sharp or blunt - a tactile capability that can be achieved when the skin is both relaxed and extended. Further unique advantages of the human skin sensory system include its location specificity. With regard to external forces, human skin can simultaneously identify whether pressure is being applied by a sharp or a blunt object.

Successfully mimicking this sort of tactile precision is a challenge, but when successful, could lead to great advancements in prosthetics, wearable sensors, electronic skin, touch-on flexible displays, soft robotics and energy harvesting.

Past research has shown that it is impractical to mimic the tactile function of human skin by using pixelated sensors. Other investigations have examined various carbon nanotubes, graphene, nanowires, nanoparticles and conductive polymers, but none have achieved the sensory accuracy of human skin in a highly specific manner.

### How do chemical engineers contribute?

A team of chemical engineers from Monash University have had promising results in the development of a stretchable skin that can be used to monitor a wide variety of medical conditions. The electronic skin contains a new tactile electronic skin sensor based on staircase-like vertically aligned gold nanowires (V-AuNWs) that send signals to smart phones. With a back-to-back linear or spiral assembly of two staircase structures into a single sensor, the sensors could recognise pressure in a highly location-specific manner for both non-stretched and stretched states (up to 50% strain).

In this ground breaking study, the team could demonstrate that a staircase-like design can be extended to other configurations, such as spiral and concentric patterns. When a concentric pattern with antiparallel staircase V-AuNWs is attached to a human finger, a sharp or blunt object can be discriminated in a similar way to human skin.

This thin bandaid-like 'wearable skin' is surprisingly resilient, designed to be highly stretchable and thus does not break or tear. The wearability of the electronic skin means it can be used to track a range of health issues, including blood pressure, cholesterol and glucose levels.

### What is the impact?

The wearable skin can be attached to the face and with bluetooth compatible sensors, skin muscle movement can be detected, for example facial expressions relating to autism disorder. Another form of the skin can be used to monitor hand movements, allowing for better monitoring of elderly people with conditions like dementia. Pregnant women could use the electronic skin to observe their baby's movements in the womb.

This research opens up a new route to highly specific second-skin-like tactile sensors for electronic skin (E-skin) applications.

Medical trials have been conducted and the search is ready for commercial backing. The researchers believe that some forms of the skin could be on the market within one or two years if sufficient funding is secured.

***The wearability of the electronic skin means it can be used to track a range of health issues, including blood pressure, cholesterol and glucose levels. Gold can be highly stretchable so when you stretch it, it doesn't break, it doesn't tear, it doesn't come off.***

*Contributor:*
*Professor Wenlong Cheng*
*(Monash University)*

# Understanding ACL failure mechanisms

**Using AFM–infrared spectroscopy and collagen hybridising peptide binding, researchers have revealed that ACL injury is a result of an unravelling of the collagen molecular triple helix.**

## Understanding ACL failure mechanisms

### What is the challenge?

Nearly three-quarters of all anterior cruciate ligament (ACL) injuries occur without contact while athletes are performing routine athletic manuevers in sports such as Rugby Union, Soccer and American Football, rather than from a single overload event. Over 250,000 ACL injuries occur annually in the USA, with an estimated life time cost of $10 billion. ACL injury is also a major public health concern in Australia with 197,557 ACL reconstruction (ACLR) surgeries performed in the period of 2000 – 2015, where boys and girls aged 5 – 14 years old had the most rapid increase in the rate of ACLR. ACL injuries result in negative long term consequences including early onset of osteoarthritis.

Hypotheses proposed to explain the mechanism of non-contact ACL injury include aggressive quadriceps loading, excessive joint compressive loading, awkward landing or decelerating manoeuvres, neuromuscular control deficit, and the induction of macroscopic tissue damage from repetitive submaximal ligament loading after simulated strenuous jump landings. Most studies focus on acute triggers of ACL injury. Fewer studies have explored the development of preinjury ACL damage caused by repetitive submaximal loading.

The ACL consists of dense connective tissue whose major component is type I collagen. Fibril-forming collagen molecules are assembled in a hierarchical order into ligaments. This hierarchical assembly starts with collagen molecules aggregating to collagen fibrils at the nanometer scale, then at the micrometer scale, and eventually into bundles to form ligaments at the macroscale. Disruption of the collagen assembly results in reduced tensile strength and abnormal development of the collagen fibrils.

Magnetic resonance imaging (MRI) is still the most commonly used tool for the clinical diagnosis of an ACL injury, with the potential to detect molecular, nanolevel, and microlevel damage. However the challenge of conducting the appropriate MRI test and interpreting those results remains.

Widely used research techniques to characterise ACL 'microdamage' include micro–computed tomography and histology, however these methods fail to inform on any submicrometer ACL damage that might exist.

***This initial study suggests material fatigue of the ACL could play a role in roughly 75% of all failures classified as noncontact injuries.***

### How do chemical engineers contribute?

To test their hypothesis that a non-contact ACL failure mechanism can be caused by accumulated tissue fatigue damage, a team of chemical and biomedical engineers in Australia and the USA looked for specific chemical and structural evidence of this fatigue process.

In a controlled laboratory study, the team examined adult knees by repeatedly loading the knees with four times the body weight and with simulated pivot landings known to strain the ACL. The other, unloaded knee was used as a comparison.

The chemical and structural changes associated with this repetitive loading were characterised at the ACL femoral enthesis at multiple collagen levels using atomic force microscopy (AFM), AFM–infrared spectroscopy, molecular targeting with a fluorescently labelled collagen hybridising peptide, and second harmonic imaging microscopy.

Explants from the injured knee of five patients with non-contact ACL failure were also characterised via similar methods.

Using AFM–infrared spectroscopy and collagen hybridising peptide binding, the research revealed that the injury was a result of an unravelling of the collagen molecular triple helix. AFM detected disruption of collagen fibrils in the forms of reduced topographical surface thickness and the induction of ~30- to 100-nm voids in the collagen fibril matrix for mechanically tested samples.

Furthermore, harmonic imaging microscopy detected the induction of ~10- to 100-mm regions where the noncentrosymmetric structure of collagen had been disrupted.

These mechanically induced changes, ranging from molecular to microscale disruption of normal collagen structure, represent a previously unreported aspect of tissue fatigue damage in non-contact ACL failure.

### What is the impact?

As Australia has the highest rates of ACL reconstructions in the world, and they are being reported in younger and younger athletes, some as young as seven or eight, understanding the exact nature of the injury will have a major impact on treatment, recovery and prevention. This initial study suggests material fatigue of the ACL could play a role in the roughly 75% of all failures classified as non-contact injuries.

The wider perspective of the nature of multiscale damage from tissue fatigue is important for the design of future studies to understand the physiological repair mechanism of this damage as well as the changes in biomechanics that lead to ACL failure.

*Contributor:*
*Professor Mark Banaszak Holl*
*(Monash University)*

# Developing clinically relevant biosensors

**A team at Monash University are developing new biosensors that can be used to monitor disease-related biomarkers in real-time either in an extracted blood/tissue sample, or *in vivo*.**

## Blood, sweat, and tears: developing clinically relevant biosensors

### What is the challenge?

*In vivo* biosensing has the potential to revolutionise health care by enabling personalised medicine – realising the ideal concept of a simple sensor implant that transmits clinically relevant health information on a continuous basis. Through constant monitoring, an individual's baseline health can be well understood, with small fluctuations becoming meaningful indicators of impending disease. Such an outcome could have a major impact on many aspects of public health, including challenges posed in rural and remote areas, and in home health monitoring, for example in diabetic patients.

Biosensor technology can be applied in a variety of other clinical settings including the emergency situation, where urgent diagnostic information will change the course of treatment, the hospital inpatient setting where immediate results are vital, and the outpatient setting where a test result is required to dictate overall treatment plans.

Furthermore, biosensors could transform medical care in low-resource settings without the need for highly trained medical staff, and have the potential to greatly improve patient care in disease outbreaks where complex sample handling is undesirable (e.g. the recent West African Ebola epidemic).

Despite efforts in biosensor development to provide rapid, quantitative, diagnostic information to clinicians – with the exception of glucose monitoring - no single technology or approach has been able to accomplish all the analytical requirements for *in vivo* sensing or biosensing. Technologies often show promise on the bench top but do not translate to robust *in vivo* measurements, showing signs of signal drift or reduced performance.

### How do chemical engineers contribute?

A team at Monash University, under the leadership of Dr Simon Corrie, is developing new biosensors that can be used to monitor disease-related biomarkers in real-time, either in an extracted blood/tissue sample, or *in vivo*.

The team design sensors that can carry out complex chemistry/biochemistry monitoring, while being rapid and very simple to use, as opposed to multi-step immunoassays, which are very common but take hours to get a result and require trained laboratory scientists. To make treatment decisions, clinicians need information, and currently expensive and time-consuming laboratory testing is the only source of reliable information.

For example, in Victoria alone, 80,000 people present to hospital each year with heart-related pain, but only ~15% need urgent treatment. A key indicator of those needing treatment is the concentration of cardiac troponin in the blood, which could be measured quickly and reliably with an *in vivo* sensor.

The research goal is to implant sensors into high risk individuals, enabling early detection of the presence of a disease-related biomarker, and/or can monitor the change in the level of a biomarker – allowing clinicians to then react quickly to the new information.

### What is the impact?

This work is finding new approaches for rapid detection of bloodstream infections in high risk patients, for monitoring response to treatment and disease recurrence in cancer patients, and monitoring the health and viability of cells grown in 3D scaffolds for tissue engineering or cellular therapies.

Since moving to Monash in 2016, several clinical collaborations have been established with the Alfred Hospital and at Memorial Sloan Kettering Cancer Centre in New York for monitoring cardiac biomarkers (troponin) and cancer biomarkers (e.g. epidermal growth factor receptors).

This multidisciplinary group continues to expand and always welcomes new highly motivated students with backgrounds ranging from engineering to physical, biomedical and clinical sciences.

***In Victoria, 80,000 people present to hospital each year with heart-related pain, but only ~15% need urgent treatment - the key piece of information is cardiac troponin concentration in the blood, which currently can only be done in a hospital laboratory.***

*Contributor:*
*Dr Simon Corrie*
*(Monash University)*

# waste management

THERMAL RECYCLING OF WASTE PLASTICS

FROM WASTE TO FUEL AND CHEMICALS

**In addressing the burden of waste on our environment, chemical engineers investigate ways in which waste can become useful, applying principals of the circular economy.**

**In pursuing this, waste is reduced back down to its usable size using mechanical, thermal or chemical means.**

**As most plastics are produced from oil, the recycling of plastic and rubber wastes is of increasing importance.**


# Thermal recycling of waste plastics

**Murdoch university researchers set themselves the challenge of solving two crucial environmental problems: to develop a sustainable solution to NOx emission, and to provide additional means of dealing with excessive plastic wastes.**

## Cutting-edge approaches toward thermal recycling of waste plastics

### What is the challenge?

Apart from their limited industrial and medical applications, oxides of nitrogen (NOx) contribute to acid rain, eco-eutrophication, photochemical smog, ground level ozone, the greenhouse effect, stratospheric ozone depletion, and health deterioration (for example chronic respiratory and obstructive pulmonary dysfunction) of predisposed organisms. The quest for the reliable reduction of NOx - formed in thermal processes using recycled plastics such as polyethylene (PE) - has led to the implementation of strict environmental regulations and development of industrial-scale technologies. However, some of these approaches are not economically viable and often rely on the deployment of heterogeneous catalysis systems that are prone to rapid deactivation.

### How do chemical engineers contribute?

Fuel reburning is a commercially available technological retrofit technology that appears to be more effective than alternative modifications of combustion processes. The process abates NOx by using fuel as a reducing agent. Although, large-scale reburning systems usually rely on hydrocarbon gases (e.g. methane), solid carbonaceous residues have proven equally suitable. Owing to its high calorific value, good volatile content and favourable combustion rate, waste polyethylene has been identified as a feasible reburning fuel.

At the Fire Safety and Combustion Kinetics Laboratory at Murdoch University, research is being conducted on thermal mitigation of NOx with PE. The team has found that, waste PE can potentially serve to reduce NOx emissions in industrial activities. Experiments involve sample characterisation, and thermogravimetric decomposition of PE under controlled atmospheric conditions, with NOx concentration relevant to industrial applications. TGA–Fourier transform infrared (FTIR) spectroscopy and NOx chemiluminescence measured the removal efficiency of NOx by fragments of pyrolyzing PE. Typically NOx removal efficiency amounts to 80%. Results from TGA-FTIR measurements were validated against accurate quantum chemical calculations. A robust kinetic model was formulated to account for the salient features of this NOx thermal abatement strategy.

### What is the impact?

Research on thermal decomposition of PE in NOx doped atmosphere provided a detailed analysis of reaction products. The insights from this investigation apply equally to the abatement of NOx with materials laden with PE, polyolefins/paraffins and pure carbon–hydrogen-type polymers, as well as to co-combustion/pyrolysis of PE with nitrogen-rich fuels such as biomass and coal. A cost evaluation revealed the relative financial feasibility of waste PE as a reburning fuel, identifying it as a competitive (and sustainable) alternative to other fuels. PE reburning compares favourably to other popular technologies, such as the selective catalytic reduction (SCR). The use of waste plastics as reburning fuel can also attract financial incentives from local authorities (e.g. green certificates), lowering the overall functional cost.

***This research achieved an excellent NOx removal efficiency of about 80%. These findings reinforce abatement of NOx by thermal recycling of olefin polymers as a sustainable alternative to other fuels. Most importantly, results find direct applications in reducing emission of NOx gases from mining-related activities.***

*Contributors:*
*A/Prof Mohammednoor Altarawneh, A/Prof Gamini Senanayake, & Dr Ibukun Oluwoye (Murdoch University)*
*(Pictured: A/Prof Mohammednoor Altarawneh with student)*

# From waste to fuel and chemicals

**A group at Monash University is exploring the processing of waste tyres, waste mixed plastics, electronic wastes and waste optical fibres for energy (oil and energetic gas), chemicals, monomers and metal recovery, with promising results.**

# waste management

## From waste to fuel and chemicals

### What is the challenge?

Now that Australia's waste export options have been closed, the country must find its own solutions to the 43 million + tonnes of solid waste produced each year.

Add to this the 56.3 million equivalent passenger unit (EPU) of end-of-life tyres that ended up in the waste stream in 2015-2016, of which 60-65 % went to landfill, and the vast volumes of electronic devices, replaced at an accelerating rate.

Furthermore, the world is generating tens of millions of e-waste per year. Waste electronic and electrical equipment contains metals embedded into plastics and toxic adhesives. These precious metals are valuable resources, which otherwise end up in landfill and contaminate water and soil through leaching over time. Hence, it is essential to establish an environmentally friendly and economically feasible way to efficiently recover these metals. For example, the printed circuit board (PCB) has a large metal content including copper (10-30%) as well as other metals like Ni, Zn, Fe, Pb, Ag, Au, and Al. PCBs are now recognised as the secondary resource for the recovery of base metals like Cu and precious metals like Au and Ag. However, the recycling of PCBs is limited due to the heterogeneous nature of the material. Therefore, adequate management of waste PCBs is important for resource recovery, as well as preventing their leaching in to the soil and water bodies.

The challenge is to process the waste, thus minimising landfill while generating fuels for energy and extracting chemicals or metals, following the principles of circular economy. Required in the near-term are solutions to process accumulated non-recyclable plastics into fuel, thus completely reducing landfill. In the intermediate term, we need to recover the monomers so that these are reused to remake plastics, without leaking carbon into the atmosphere.

### How do chemical engineers contribute?

The Monash group, led by Professor Bhattacharya, is exploring the processing of waste tyres, waste mixed plastics, electronic wastes and waste optical fibres for energy (oil and energetic gas), chemicals, monomers and metal recovery, with promising results.

At present, several techniques of recycling waste PCBs have been proposed including physical and mechanical separation technology, hydrometallurgical processing, pyrometallurgical method, electrodeposition, and microwave treatment. Among these recycling techniques, the combination of mechanical crushing and hydrometallurgical processing is still the most competitive and commonly used technology for waste PCBs recycling.

In one of the group's research projects, with industry support, material is shredded and sieved to <1mm size fraction. The shredded PCB waste is characterised for its composition using thermogravimetric spectrometric techniques. These are then processed through a two-stage process – separating the plastics into fuel and extracting the high-value metals through an environmentally friendly acid-treatment process. They have also demonstrated, working on a bench scale, the conversion of the plastics back to monomers – the building block for polymers. The current work is focussing on scaling up the process separating the individual metals and the monomer recovery; they are looking for further industry support.

The research on waste plastics and waste tyres is the most advanced. The team have built a business case for processing of waste plastics and tyres to obtain venture capital funding and have carried out a preliminary techno-economic analysis, including the capital costs of such a plant, all the control systems that will be necessary to run it, the manpower for three shifts on a day in day out basis, and the purchase of the feedstock supply.

### What is the impact?

Professor Bhattacharya, who came to Monash after a long career commissioning coal-fired power plants and gasification plants, is determined to translate this technology into one or more full-scale processing plants that can start taking recyclables as soon as possible. He has entered into discussions with three councils that border the university to scale up his laboratory processing facility into a plant that can handle real-world waste streams. His team has collected statistics on the volume of waste generated by the councils.

He believes it is possible to build three 10-tonne per day or one 30-tonne per day plant on land owned by any one of the three councils.

***The team have built a business case to obtain venture capital funding and have carried out a preliminary techno-economic analysis.***

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