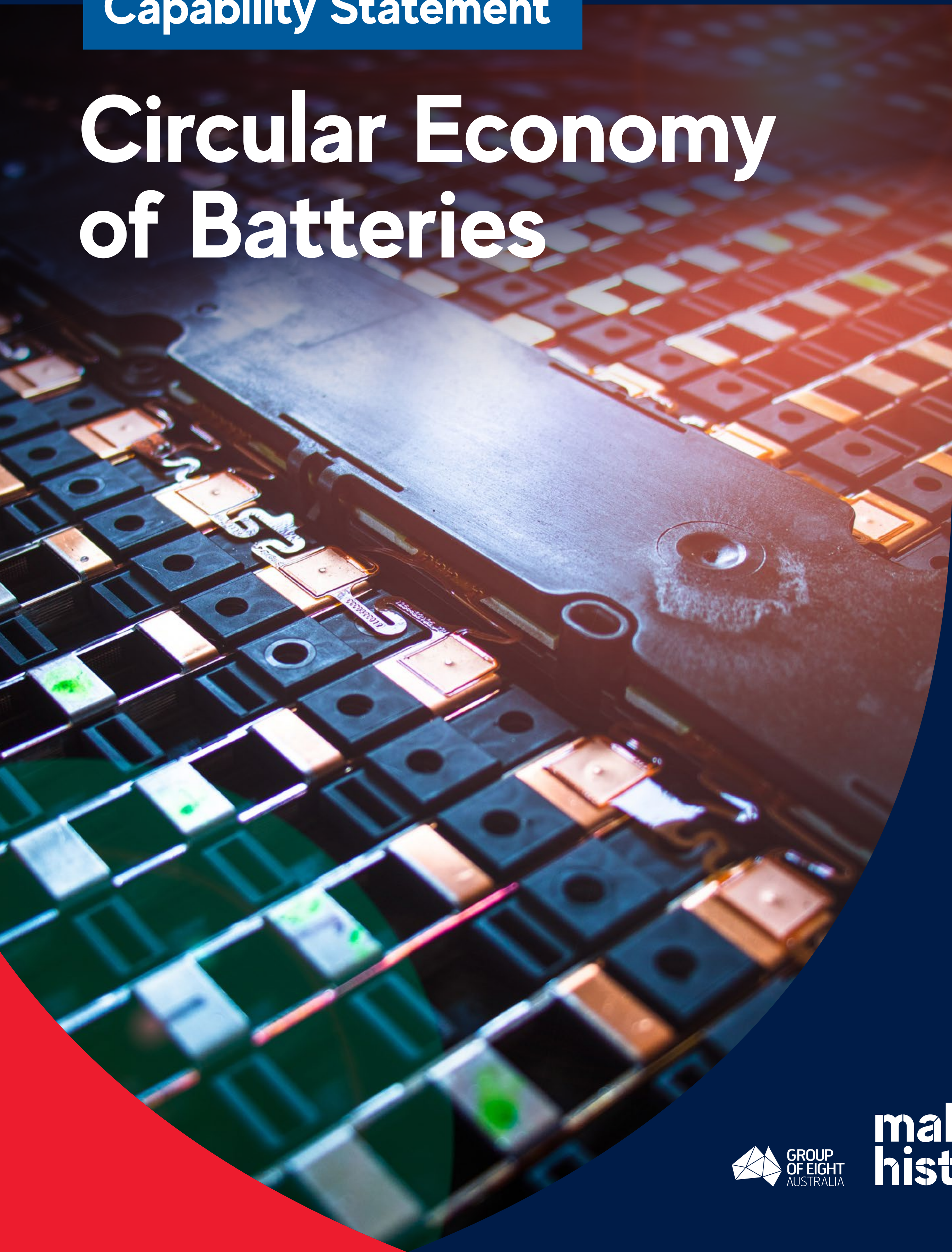
THE UNIVERSITY of ADELAIDE

Capability Statement

Circular Economy of Batteries



GROUP OF EIGHT AUSTRALIA

make history.

The School of Chemical Engineering and Advanced Materials

The School of Chemical Engineering and Advanced Materials has a strong research track record in energy storage that attracts global interest. Our researchers deliver innovative, world-class solutions for the development of the circular economy of batteries, and provide an ideal environment for industry focussed research and development.

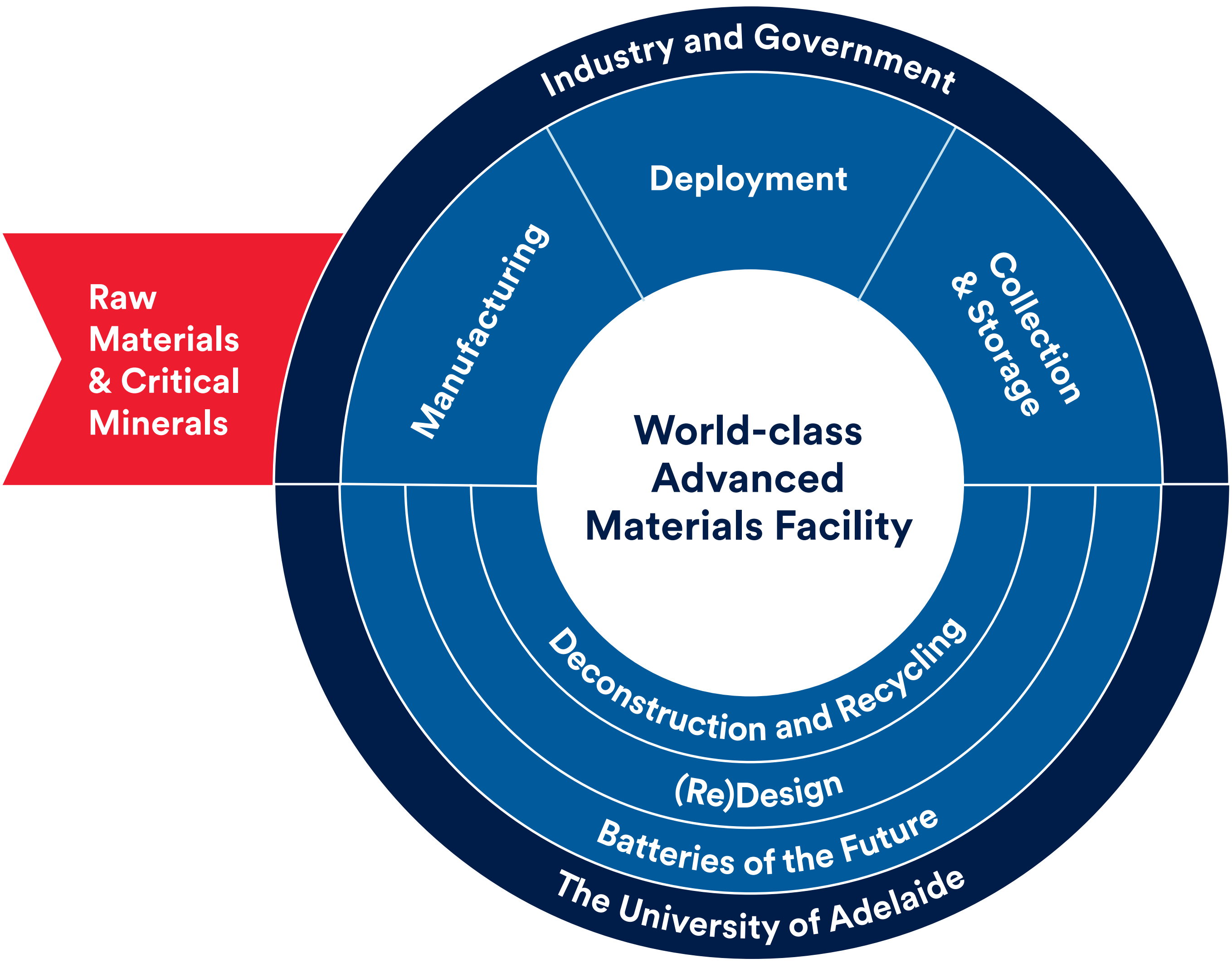
Our research capability spans from fundamental scientific discovery to laboratory prototyping to operational environments and commercialisation.

We are seeking industry and government partnerships to address problems and develop sustainable solutions for the management of batteries spanning from end-of-life Lithium-Ion Batteries recycling (today's problem) to new battery types for ready recycling (solutions for the future).

Our team comprises talented material scientists and process engineers with significant academic and industry track records, providing expertise from molecular modelling to energy materials design and synthesis to process engineering and commercial demonstration. At the University of Adelaide, the team has access to world-class research and innovation infrastructure including large-scale research facilities, equipment and instrumentation; networks of energy storage technologies and e-infrastructures, comprising data and high performance computing systems; and knowledge-based resources.

Our mission is to provide innovative technical solutions and leadership to assist industry to transition to net zero carbon emission by contributing to the immediate and future needs of energy storage, closing the loop to create the sustainable circular economy of batteries.

Closing the loop for the circular economy of batteries



Challenges in end-of-life batteries

The age of the electric transportation and mega batteries has started.

The production of Lithium Ion Batteries (LIBs) has increased rapidly in recent years. Many governments around the world have already introduced legislation to prevent the selling of internal combustion vehicles within the next few decades, and; many automotive companies plan to produce electric vehicles (EVs) only. The global EV market has grown from 40 to 70% annually since 2011, with more than 2.1 million new EVs sold in 2019.[1] Bloomberg forecasts that the annual global EV sales will continue to increase and reach 24.4 million by 2030.[2] The rapid growth in EVs will lead to significant demand for lithium-ion batteries (LIBs). Global battery consumption is expected to grow by 25% annually to 2.6 GWh in 2030.[3]

It is estimated that the spent LIBs will grow to between 100,000 and 188,000 tonnes in Australia by 2036, and the recoverable value would be between AU$681 million and AU$2.5 billion.[4] This has led to a direct increase in the exploitation of mineral deposits to provide the raw materials required by the LIB market. Recycling of end-of-life LIBs represents an untapped source of valuable materials. From an environmental standpoint, end-of-life LIBs contain heavy metals cobalt and nickel which can be toxic to our ecosystem. In addition, there are large concerns over safety of stockpiles of end-of-life LIBs due to fire and explosion risks. Hence it is critical to find solutions to the problem of recycling end of life LIBs.

Australia is presently well-positioned to capitalise on the rapidly emerging global transition to EVs. Therefore, it is both timely and necessary for university-researchers and industry to work together fostering a future research workforce with capacity to develop economic battery recycling.

1. The global electric vehicle market in 2020: statistics & forecasts.
2. We're Going to Need More Lithium. Bloomberg Businessweek.
3. A Vision for a Sustainable Battery Value Chain in 2030: Unlocking the Full Potential to Power Sustainable Development and Climate Change Mitigation.
4. Lithium battery recycling in Australia: defining the status and identifying opportunities for the development of a new industry. *Journal of Cleaner Production*, 2019. 215, 1279-1287.

Photo courtesy: Parilov - stock.adobe.com

Our plans to address the challenges

Recycling of batteries requires both near-term and long-term solutions.

A near-term solution will take advantage of existing infrastructure and is ready to be implemented; and a long-term solution will provide a more sustainable alternative which takes longer to implement.

Near-term solution: *Processing end-of-life Lithium Ion Batteries in existing smelters*

Recycling of LIBs to extract metals involves two main stages: a pre-processing and mechanical (sorting, liberating, classifying and concentrating materials) stage, and a processing stage by either hydrometallurgical method and/or pyro-metallurgical methods.

Many processes have already been developed and demonstrated at significant scales. Before the volume of spent LIBs meets a level that warrants dedicated investment, we can take advantage of existing smelters, e.g. **Nyrstar Port Pirie Smelter** in South Australia. To make this happen, the pre-processing, pyrometallurgical and hydrometallurgical processes - which are already undertaken at the Port Pirie smelter- needs to be understood and re-designed, as well as the technical, environmental and economic feasibility demonstrated. The process needs to appropriate to prepare a feed to a smelter that can be processed in existing plant and equipment. The process will also be required to take products from the smelter for further refining in order to produce a saleable product (for example Li, Ni, Mn, Al which are not currently produced at Port Pirie).

Long-term solution: *New materials recycling process and New batteries*

For the battery recycling to be competitive and achievable at scale, it is necessary to have 'green' and cost-effective battery recycling technologies and capabilities. In the long run, we aim to designing advanced processing and manufacturing capabilities for recycling valuable battery materials, and redesigning high performance batteries to avoid disposal at battery end-of-life.

Specific objectives are:

1. Recycling of cathode materials by new efficient and sustainable processes, to recover metal elements from batteries, especially nickel, cobalt, manganese, lithium, and phosphate will increase the economic value of end-of-life batteries.

2. Recovery of other materials, such as graphite anodes, electrolyte and current collectors.

3. Upcycle and redesign of cathode materials composition to reflect the stoichiometry of more desirable cathode formulations, to increase economic value.

4. Design of new battery materials and cells for ready recycling, as currently, LIBs are not assembled with recycling in mind. Using novel materials and methods of design of battery packs, cells and materials will lead to easier recycling that maximize the profitability.

Fostering workforce through collaborations with Industry Partners

Because LIB recycling is currently small-scale globally, the number of researchers with industry relevant skills remain sorely limited. Through development of LIB recycling technologies and new batteries with Industry Partners, a skilled workforce, including graduate engineers, PhD graduates and early-career researchers, will be trained to meet industry demand. New partnerships will enable the generation of new knowledge and technologies in recovering critical elements/materials from end-of-life batteries, and reusing them in the design of new electrodes and batteries for societies future needs with energy storage.

Research with Impact

Research in Materials and Energy in the School of Chemical Engineering and Advanced Materials (CEAM), the University of Adelaide is world-class.

CEAM has achieved a rating of 5 (well above world standard; highest rating) by Excellence in Research Australia[1] in three disciplines: Chemical Engineering, Materials Engineering, and Nanotechnology. Overall, 12 laboratories are available to support the relevant research activities, including a new 350 m^2 in-situ characterisation laboratory established in 2021 to support the university's energy materials research.

This new $10M facility enables the university to continue to build its reputation as a global leader in renewable energy and energy storage R&D. Additional Materials & Energy laboratories, with state-of-the-art equipment, are under construction and will become available in 2022.

The relevant research in energy storage will be led by a strong team, including two Australian Laureate Fellows[2], Prof Shizhang Qiao and Prof Zaiping Guo. Their respective groups have established an international network of academic and industry partners, contributing to commercialisation and industry development via technology transfer, spin-off and start-up companies established by former PhD graduates.[3]

The overall research team (see next section for more information) is multidisciplinary with complementary skill sets to address all critical aspects of battery recycling. The team can investigate the battery recycling problems from the atomic level to the processing level. In total, the team has published > 900 refereed papers in high-quality journals, including *Nature*[4] and its sister journals.

The team has well-equipped with cutting-edge facilities that are required for battery and materials research, including the more than AU$20 million funding support from the Australian Research Council through Research Fellowships, Research Hub, Discovery, Linkage and LIEF programs. A list of selected projects are:

- Research Hub in New Safe and Reliable Energy Storage and Conversion Technologies, ARC Industrial Transformation Research Hub, IH200100035.
- Next generation of batteries for a sustainable future. ARC Laureate Fellowship, FL210100050.
- Solar-driven sustainable production of fuels and chemicals. ARC Laureate Fellowship, FL170100154.
- Batteries of the future-a new strategy for CO_2 fixation and energy storage, ARC Discovery Projects, DP210101486.
- Low cost aqueous rechargeable zinc batteries for grid-scale energy storage. ARC Discovery Projects, DP200101862.
- Develop catalyst materials for future fuels by operando computation, ARC Future Fellowship, FT190100636.
- High energy density, long life, safe lithium-Ion battery for electric cars. ARC Linkage Projects, LP160101629.

1. Administered by Australian Research Council (ARC)
2. This fellowship is highly competitive, and is only awarded to 15 research leaders every year national wide.
3. For example, Professor Qiao has secured an AU$1 million research contract from Zhuoyue Power New Energy Ltd to commercialise their patented battery technology. Professor Guo collaborated with NSW-based Sicona Battery Technologies Pty Ltd to develop pilot-scale production of silicon/carbon/graphite composite materials and binders for EV battery application.
4. First published in 1869, *Nature* is the world's leading multidisciplinary science journal.

Our World-Leading Experts

Professor Shizhang Qiao

ARC Laureate Fellow, Inaugural Chair of Nanotechnology, Founding Director of Centre for Materials in Energy and Catalysis (CMEC), at the University of Adelaide. Fellow of Institution of Chemical Engineers (FIChemE), Royal Society of Chemistry (FRSC) and Royal Australian Chemical Institute (FRACI).

Professor Shizhang Qiao is one of the first international scientists in energy research to seamlessly combine experimentation and theoretical computation by pioneering the 'computation-guided material and catalyst design' principle, which has significant implications for fundamental studies and the practical application of electrocatalysis, photocatalysis and batteries. He and his team's transformative work in materials science for energy conversion and storage technologies successfully brings together materials engineering, physical chemistry, electrochemistry and quantum chemistry. He has co-authored more than 460 papers in refereed journals, including *Nature*. His publications have attracted more than 86,000 citations with h-index 152.

In recognition of his research achievements, he was honoured with a finalist of South Australian Scientist of the Year (2021), IAAM Medal (International Association of Advanced Materials, 2021), inaugural UoA Vice-Chancellor's Award for Excellence in Research (2019), an Australian Star of Research (Lifetime Achievers Leader Board, by *The Australian* 2019-2021), prestigious ARC Australian Laureate Fellow (2017), ExxonMobil Award (2016), ARC Discovery Outstanding Researcher Award (DORA, 2013), and Emerging Researcher Award (2013, ENFL Division of the American Chemical Society).

He has filed five patents on novel nanomaterials and attracted more than $15 million in research grants from industrial partners and the Australian Research Council (ARC).

His overall strategic leadership will contribute greatly to the success of establishing South Australia as a hub in battery recycling program.

Professor Zaiping Guo

ARC Laureate Fellow at the School of Chemical Engineering and Advanced Materials, the University of Adelaide, and Deputy Director of the SafeREnergy Research Hub.

Professor Zaiping Guo is a world-leading materials scientist working in the field of energy storage. Her research focuses on the design and application of electrode materials and electrolyte for rechargeable batteries. Her theoretical and experimental research on the interactions between electrolytes and electrodes for batteries is globally recognised and highly respected.

She has established an international network of academic and industry partners, contributing to commercialisation and industry development via technology transfer, spin-off companies, and start-up companies established by former PhD graduates. She is also a Key CI in the AutoCRC 2020 program contributing to the optimisation of batteries for electric cars.

Zaiping has published more than 350 papers based on her research in rechargeable batteries in high quality journals, and is an inventor or co-inventor on eight patents. Her research is actively shaping the energy storage discipline, as is evident in her career citation metrics (Google Scholar citations > 32,900, h-index of 97) and led to her recognition in 2018, 2019, 2020, and 2021 as a Clarivate Analytics Highly Cited Researcher.

As a result of her pioneering and internationally acclaimed work on rechargeable batteries, she was awarded an ARC QEII Fellowship (2010), an ARC Future Fellowship (FT3, 2015), and an ARC Laureate Fellowship (2021). She was also awarded 2020 NSW Premier's Prizes for Science and Engineering for Excellence in Engineering or Information and Communications Technology.

As a battery specialist, Zaiping will contribute greatly to the success of the Battery Recycling Program, through her continued research and development of cost-effective, environmentally sustainable strategies for dealing with the vast stockpile of spent lithium-ion batteries.

Professor David Lewis

Head of the School of Chemical Engineering and Advanced Materials, the University of Adelaide

David began his engineering career in the Royal Australian Navy as an Electrical Technical Weapons rating with an Electrical Fitter Mechanic trade qualification. He worked in the Weapons Electrical Engineering Branch on HMAS Brisbane maintaining and operating the weapons systems including the Tartar and Ikara guided missile systems. He ended his trade career as an electrical technician with SAGE Automation building and installing robotic systems in the automotive industry before commencing a career in Chemical Engineering.

As an experienced Chartered Chemical Engineer and Fellow of the Institute of Chemical Engineers, David's industry and academic careers have provided him the opportunity to work in the petroleum, mining, automation, hospitality, and defence industries on product and manufacturing design and optimisation. David's research activities have focussed on renewable energy systems, and with his electrical and process engineering background is well placed to address the circular economy of batteries. Between academic and industry positions David has published ~90 peer-reviewed scientific journal papers and 3 patents, has a H-index of 25 with over 3200 citations, and has led many significant public-private partnership funded research projects in the area of renewable energy.

Associate Professor Yan Jiao

ARC Future Fellow, Director of Research in School of Chemical Engineering and Advanced Materials, at the University of Adelaide

Associate Professor Jiao's research interest is the design of energy materials – including battery materials – by computation methods such as Quantum Chemistry based calculation and Molecular Dynamics simulation. A/Prof Jiao has attracted more than one million Australian dollars in research grants as the first CI. This includes an ARC Discovery Project as lead CI (Design of Electrocatalysts for Hydrogen-Free Ammonia Production under Ambient Conditions), an ARC Future Fellowship (Develop Catalyst Materials for Future Fuels by Operando Computation), and a highly competitive Vice Chancellor's Research Fellowship (DFT Aided Material Design for Solar-Fuel Generation). A/Prof Jiao has published more than 80 research papers in top tier journals, including *Nature* sister journals, and a book chapter. These works have collectively attracted more than 21,000 citations (h-index of 50).

A/Prof Jiao has won a list of awards. She was recognised as a Highly Cited Researcher (an award to recognize researchers with significant influence in their academic field) in Chemistry by Clarivate Analytics in 2019, 2020 and 2021. She received UoA Women's Research Excellence Award in 2015. She was recognised as one of the 40 Rising Stars in research by *The Australian* in 2019. She received the Young Tall Poppy Award in 2020. She was one of the 2021 South Australia Women of the Year Finalist.

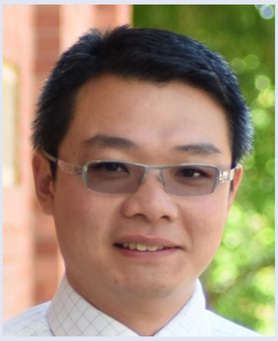
Dr Philip van Eyk

Director of Learning and Teaching in the School of Chemical Engineering and Advanced Materials, at the University of Adelaide

Dr van Eyk's research principally involves the application of fundamental process engineering principles to many new and emerging technologies. Dr van Eyk has predominantly worked on industrially relevant research projects that have led to positive outcomes for industry partners.

Philip's research has involved a wide spectrum of scales over the years; from the design and operation of lab scale and pilot scale plants to demonstrate new processes, to process and techno-economic modelling of novel systems. Previous projects include demonstration of pilot scale gasification of solid fuels with the aim of producing replacements for crude oil; lab scale and technoeconomic assessments of combing solar energy with gasification of biomass to produce sustainable fuels; development of high temperature and pressure reactors for processing sewage sludge; agricultural wastes and plastics to produce valuable products; and developing processes for using solar thermal heat as a replacement for fossil fuel combustion in industrial processes (e.g. alumina production).

Dr van Eyk will bring many years of experience in many fields of process engineering both from an experimental and modelling standpoint, to ensure that the project will have successful outcomes towards industrial application.



Associate Professor Philip Kwong

Director of Internationalisation in the School of Chemical Engineering and Advanced Materials, at the University of Adelaide

A/Prof Kwong has made significant contributions in the field of sustainable waste management and resource recovery from waste resources to support the growth of future industries around circular economy goals. He has extensive experience in air pollution control, waste management, catalysis, and biomass energy generation. He is particularly interested in converting waste materials into value-added functional products for environmental mitigations and energy generations.

He has published more than 60 articles in high-impact journals, peer reviewed conferences, and technical reports, attracting over 1500 citations with h-index of 19. Over 90% of the publications are in the top journals in his field. He was also awarded a prestigious invitation fellowship by the Japan Society for Promotion of Science for recovering valuable resources from sewage sludge.

Philip's world-leading expertise in resource recovery from biomass has recently been transferred into international patents. This has led to his establishment of a technology start-up company that has attracted more than $1.5 million in investment since 2018.

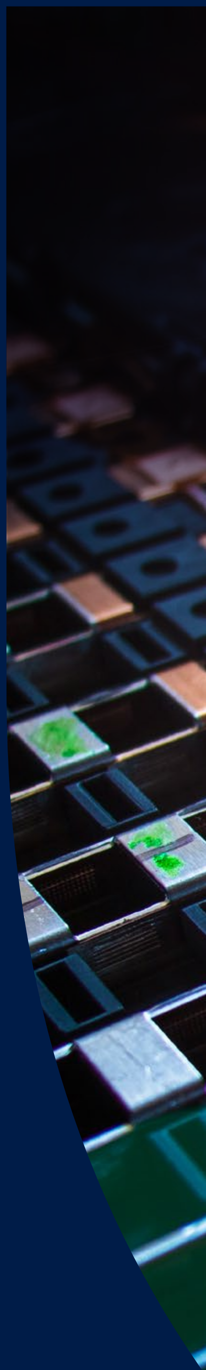
Philip's pioneered technology has been utilised around Australia in different industries to produce low-cost activated carbon from various waste agricultural resources. His technology has been named as one of the "10 Australian inventions equipping us for the future" by The Brilliant.

Based on Philip's expertise in waste biomass resource recovery, he has recently contributed to sustainable battery recycling technology by developing a quick and environmentally benign continuous method to recover valuable metal resources from spent lithium-ion batteries.

It is both timely and necessary for university-researchers and industry to work together fostering a future research workforce with capacity to develop economic battery recycling.

Kaurna acknowledgement

We acknowledge and pay our respects to the Kaurna people, the original custodians of the Adelaide Plains and the land on which the University of Adelaide's campuses at North Terrace, Waite, and Roseworthy are built. We acknowledge the deep feelings of attachment and relationship of the Kaurna people to country and we respect and value their past, present and ongoing connection to the land and cultural beliefs. The University continues to develop respectful and reciprocal relationships with all Indigenous peoples in Australia, and with other Indigenous peoples throughout the world.



Find out how we can help

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