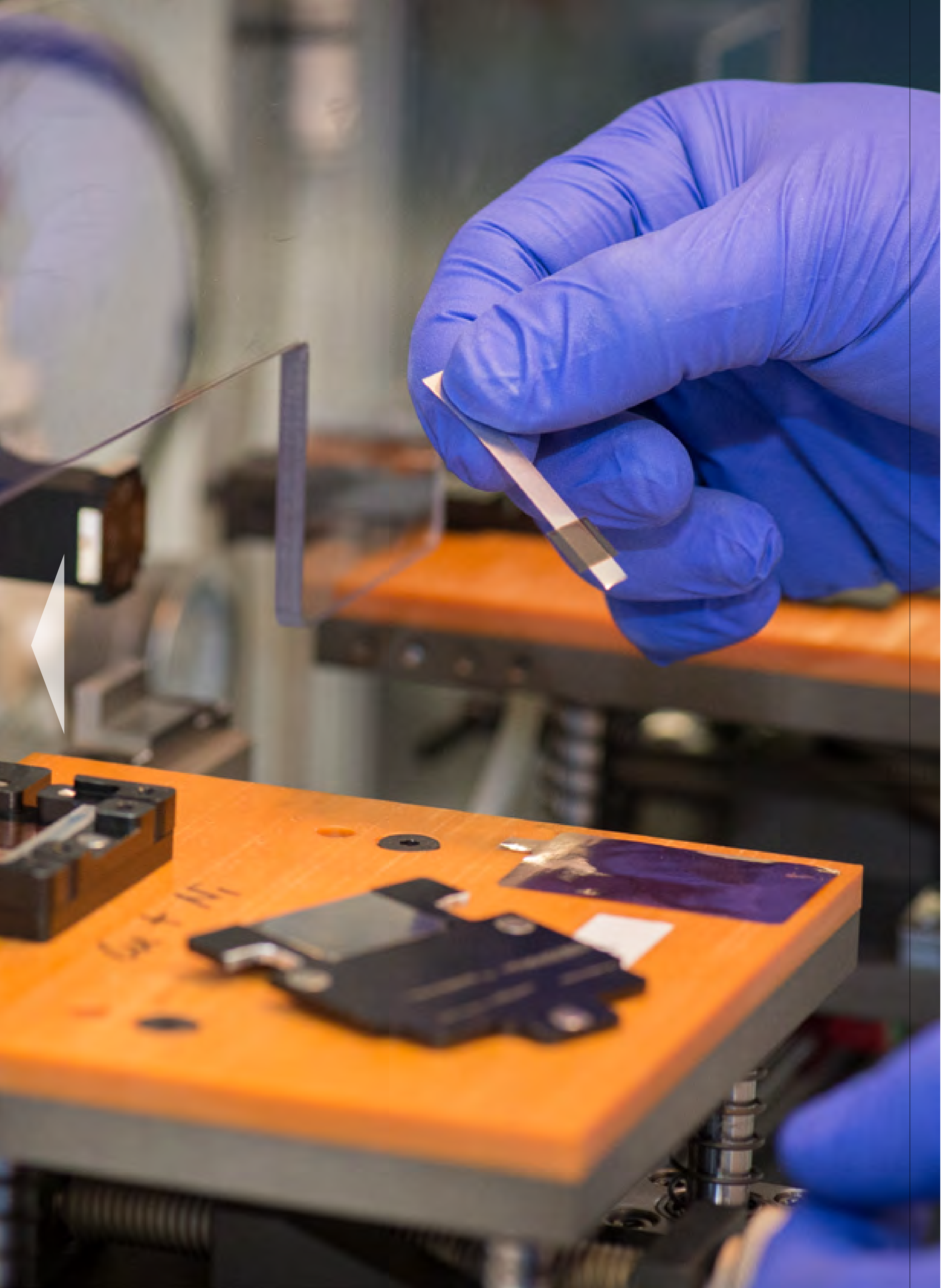
NEW DIMENSIONS 2019

INTERACTIVE

Investigate. Innovate. Translate.

TRANSITIONING FUNDAMENTAL RESEARCH TO STRATEGIC APPLICATIONS



Introduction

PROFESSOR GORDON WALLACE – DIRECTOR’S ADDRESS

We are in the midst of a revolution. Researchers are at the forefront of technological, clinical and industry breakthroughs. Where once we worked in silos, now we are working alongside end-users, industry, and regulatory experts to bring better outcomes to the communities we work for.

At **ACES**, this approach is central to everything we do. We are honing our technical skills, but we also recognise that those skills alone will not see our knowledge of advanced materials turned into next generation products.

We must break through traditional academic boundaries to confront significant issues in the real world creating teams of highly skilled individuals who can acquire the ability to communicate outside their field of expertise.

At ACES, we have a focus on taking knowledge accrued from fundamental research and translating these findings into practical solutions for our communities.

- Our team at Deakin is developing a number of exciting sustainable battery and energy storage alternatives to traditional lithium ion batteries, working side by side with leading industry experts (**click** to see on page 21);
- The ACES team at Monash has significantly advanced technologies to create a transportable chemical fuel, ammonia (**click** to see on page 17);
- Researchers across ACES are working hand in hand to make the printing of body parts closer to reality to solve significant medical challenges (**click** to see on page 25);

We recognise the need to work with individuals who can help navigate the regulatory pathway, commercial development activities and ethical issues that may arise from the breakthroughs achieved in research.

We also have an active program to take our research to the world, including regular showcases hosted by Australian Ambassadors in Embassies across the globe.

Our researchers, innovators and collaborators share a vision. A vision to take ideas to industry! We want to use fundamental research and the knowledge accrued from this research as the fuel to create commercial opportunity.

I am proud of the efforts of our team to further their research while focusing on delivering practical outcomes that bring about real knowledge advancement, that results in social and economic benefits. Supported by our host institutions, ACES will forge a pathway that ensures next generation researchers can travel this journey in a more effective manner.

We look forward to continuing to work and collaborate with others to realise our vision.

Regards,

Prof Gordon Wallace

FOREWORD

Dr (Dame) Bridget Ogilvie (AC, DBE, FAA, FRS, FMedSci) – Chair of the ACES International Advisory Committee

It has been a privilege to be involved with the ARC Centre of Excellence for Electromaterials Science, from its beginnings at the Department of Chemistry at the University of Wollongong, to the organisation it is today which spans across multiple sites in Australia and internationally.

ACES is now recognised not only for its excellent research in the fundamental science of electromaterials, but also for the importance the Centre places on training and stakeholder engagement, and, most importantly, for working with industry to produce outcomes of great potential community value.

The variety of valuable outcomes described in the Director's Report is remarkable. These initiatives are addressing global problems that are highly significant and urgent, but most were not considered so at the outset of ACES in 2005.

It is clear that climate change is rapidly altering the weather resulting in unprecedented floods, droughts and other changes to the earth's environment, with rising seas threatening to engulf many cities based on estuaries and causing damage to world food production. ACES is working to produce environmentally sustainable sources of energy and energy storage, which should help to reduce the use of fossil fuels that are causing these changes in the world's climate.

From the viewpoint of individuals, research into the fabrication of body parts using customised bioink formulations and 3D printing is targeted at tackling big medical challenges. These technologies should have positive effects on medical practice such as delivering viable cells for the regeneration of conditions such as the destruction of cartilage in arthritis, and replacement of damaged nerve and pancreatic cells.

The ever-increasing need for surgical joint replacement and the incidence of diabetes is threatening to overwhelm medical services everywhere, and ACES research outcomes should help with this problem.

All these achievements have resulted not only from excellent science but also by the remarkable way members of ACES collaborate and work together. This team has invested in the future building linkages that can help solve global challenges and networks to effectively disseminate the knowledge accrued.

FOREWORD

The Hon Dan Tehan MP Minister for Education

The Australian Research Council (ARC) Centres of Excellence were introduced by the Howard Government in 2001, with the first centres funded in 2003.

Since then we have established 21 Centres of Excellence at universities around Australia to undertake highly innovative and transformational research. The centres have proved their value as prestigious focal points of expertise, with a focus on research areas of national priority.

These centres bring together experts from universities, business, government and research organisations to lift capabilities across the board and break down silos.

Having visited a number of these centres as Education Minister, I have seen first-hand the truly outstanding research they undertake.

I want to continue to celebrate the contribution our universities are making to our country.

Professor Gordon Wallace has headed up a world-leading ARC Centre of Excellence at the University of Wollongong since 2003, bringing together extremely talented researchers in electromaterials, to develop real technological breakthroughs with commercial applications.

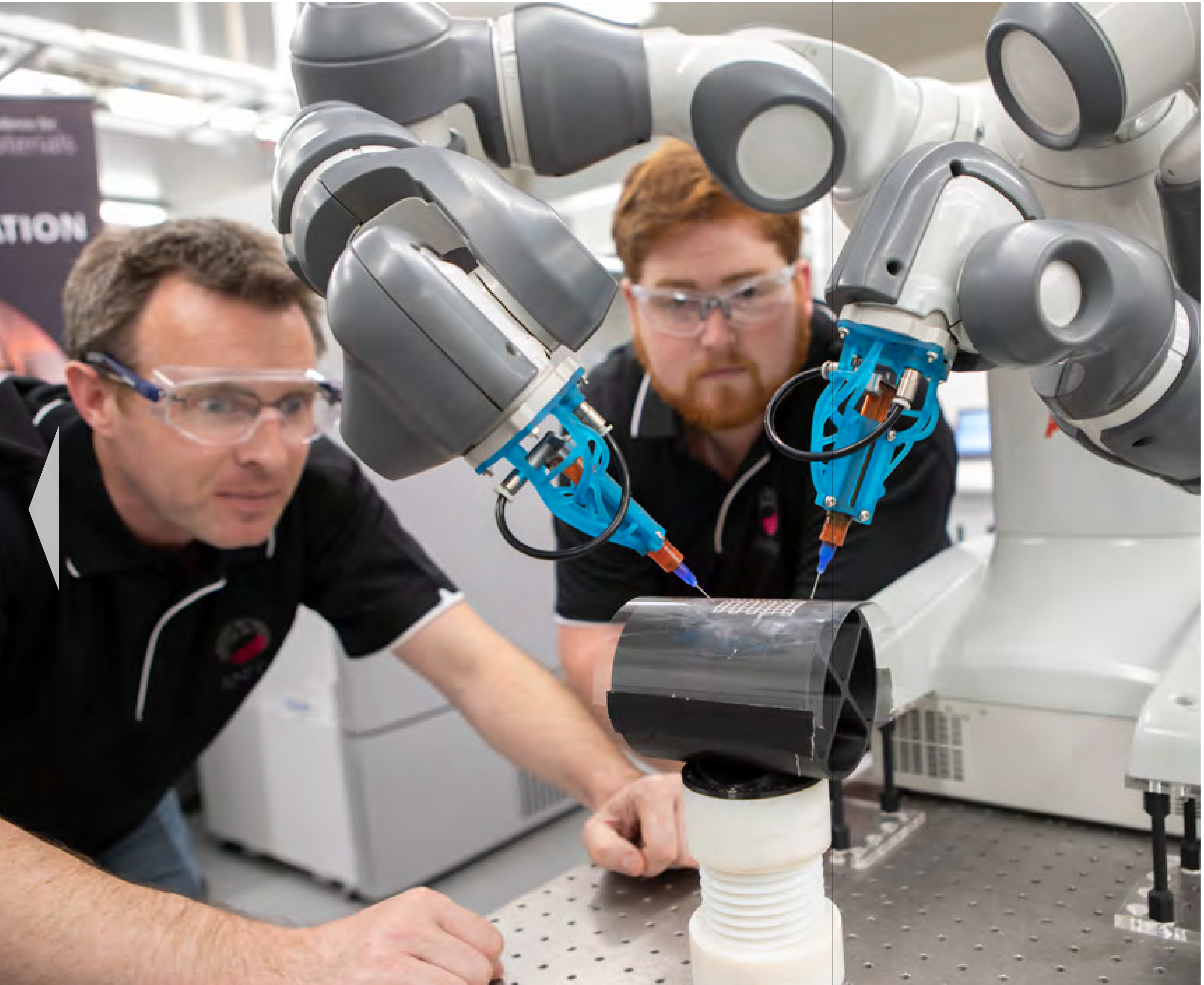
The current ARC Centre of Excellence for Electromaterials Science (ACES), established in 2014 with over $25 million in funding, has an expansive research program and is highly integrated with its partner institutes and the wider community.

As this publication demonstrates, there is an array of exciting research underway at ACES, including projects which target some of the most challenging global problems today, in areas such as clean energy, synthetic biosystems, diagnostics and soft robotics.

The Morrison Government is strategically investing in partnerships between universities, industry and government – in 2018-19 alone, we have committed $9.6 billion in science, research and innovation.

The Australian public needs to hear about the great work that researchers in our universities are undertaking with this funding because it is truly outstanding, and publications such as this are an important way to illuminate that story.

I congratulate Professor Wallace and the research team at ACES, and look forward to hearing more of their research successes in the future.



WHY WORK WITH A CENTRE OF EXCELLENCE?

Working with an Australian Research Council (ARC) Centre of Excellence is something truly special.

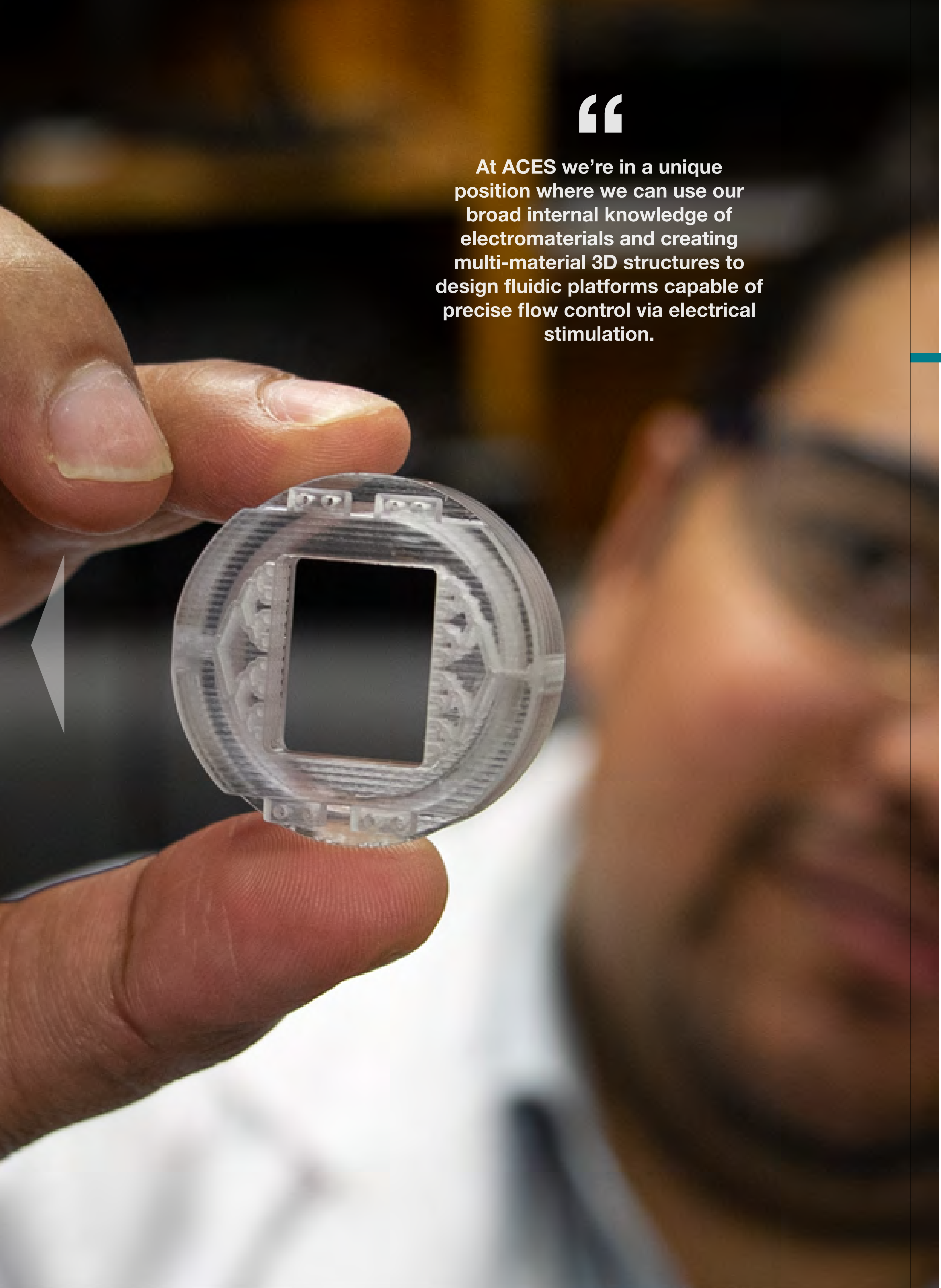
The Australian Government established the **Centre of Excellence** concept to build prestigious, internationally recognised hubs of expertise in areas of national priority that bring about breakthroughs for our most challenging research problems.

Highly talented researchers and research students from Australia and across the globe are drawn to Centres of Excellence, as they have the opportunity to tackle large-scale problems over a long period of time, with government funding surety to transform capability and knowledge in these areas. A Centre of Excellence is always looking outward, always looking beyond. Its members recognise the importance of linking existing Australian research strengths with new interdisciplinary networks to strengthen research, achieve global competitiveness and gain recognition for Australian research.

The **ARC Centre of Excellence for Electromaterials Science** (ACES) has been building its internationally-recognised research program in materials science, and its collaborative network since 2005. In this time, the Centre has established significant collaborations with major national and international centres and research programs to support outstanding research. When you work with ACES, you have access to a network of universities, research bodies, government departments, medical practitioners and clinicians, and businesses across Australia and the world, all focused on leading the charge in materials science and translating this knowledge into devices that will have a positive impact on the Australian community.

We are a balanced team of youth and experience, with diverse skills, and a commitment to success. We have established a global network of partners that is integral to our success in research, training, commercialisation and engagement. Our doors are open and we are waiting to hear from you.

We are ready and excited to provide real solutions to real world challenges.



Electrofluidics and Diagnostics

GO WITH THE FLOW: MULTIFUNCTIONAL 3D PRINTED FLUIDIC DEVICES FOR NEXT-GENERATION DIAGNOSTICS

In the laboratories of the University of Tasmania (UTAS), a small team of ACES researchers is examining the behaviour of fluids at small scales, resulting in some very BIG breakthroughs for diagnostic devices.

We’ve all seen fluids behave differently under different conditions. The predictability of a steady flow of water through a pipe at a constant rate. The volatile devastation of surging floodwater overflowing from engorged riverbanks. The ebbing glug of olive oil as it pours from the bottle to dress your favourite salad.

But have you ever considered how fluids perform at the microscale? With the drastic differences in surface tension, energy dissipation and fluidic resistance, amongst other factors, small-scale fluids do not necessarily act as they would in everyday life. Understanding these changes in behaviour are critical to developing affordable, sensitive diagnostic and sensor platforms that manipulate small volumes of fluids to control chemical, biological, and physical processes for health monitoring and drug delivery.

The ACES Electrofluidics and Diagnostics team is focused on just that – developing next-generation diagnostic platforms by leveraging advances in 3D fabrication technologies to control microfluids for applications in biomedical, industrial and environmental monitoring.

Millions of people around the world are at risk of the spread of infectious diseases, as well as acute debilitating illnesses, such as cancer. As a consequence, there is an ever-growing need for the development of portable and low cost diagnostic devices, that can potentially replace large, expensive laboratory equipment and provide in situ, at-site, and ‘at person’ results. With early and accurate diagnostics, there can be a significant improvement in prevention and increasing survivability rates, improved treatment outcomes, and ultimately reduced financial impacts.

Read more on development of portable, low cost diagnostic devices here

“At ACES we’re in a unique position where we can use our broad internal knowledge of electromaterials and creating multi-material 3D structures to design fluidic platforms capable of precise flow control via electrical stimulation,” said ACES Theme Leader for Electrofluidics and Diagnostics, **Professor Brett Paull.**

“The manipulation of fluid movement and movement of specific molecules within these fluids under an electric field (electrofluidics) is enabling advances in diagnostic systems with interrogation of our three dimensional structures containing living cells.”

Working with ACES researchers at the University of Wollongong, the UTAS team has been investigating the study and control of fluid movement upon and within fibres, both natural and synthetic, and functionalised and native. As a result of this collaboration, the team has produced novel fibres, composite fibres, and functional fibres, as well as the design and development of 3D printed fibre fluidic platforms as simple diagnostic devices.

Access Analytica Chimica Acta paper here

"We've gained insights into the flow and control of fluids upon and within functional and composite fibres through the control of an applied voltage, which have seen our research expand into new areas, including the development of several specific diagnostic assays based upon fibre-based systems, and targeted drug delivery into hydrogels," Brett said.

One of these key breakthrough areas is the team's production of 3D printed platforms for the study of fibre-based delivery into solid gels.

This achievement has provided a potential alternative approach for targeted chemical, biosensing and diagnostic devices, through the electrofluidic control of bioactive molecule delivery into soft tissue models.

As part of the work, the group introduced a low cost microfluidic textile analytical device utilising a 3D printed supporting scaffold (to mimic soft tissue in the body) and commercial threads. Using absorbable surgical sutures, the team successfully transported and controlled delivery of bioactive molecules, including drugs and proteins, with an electrical field into the soft tissue model.

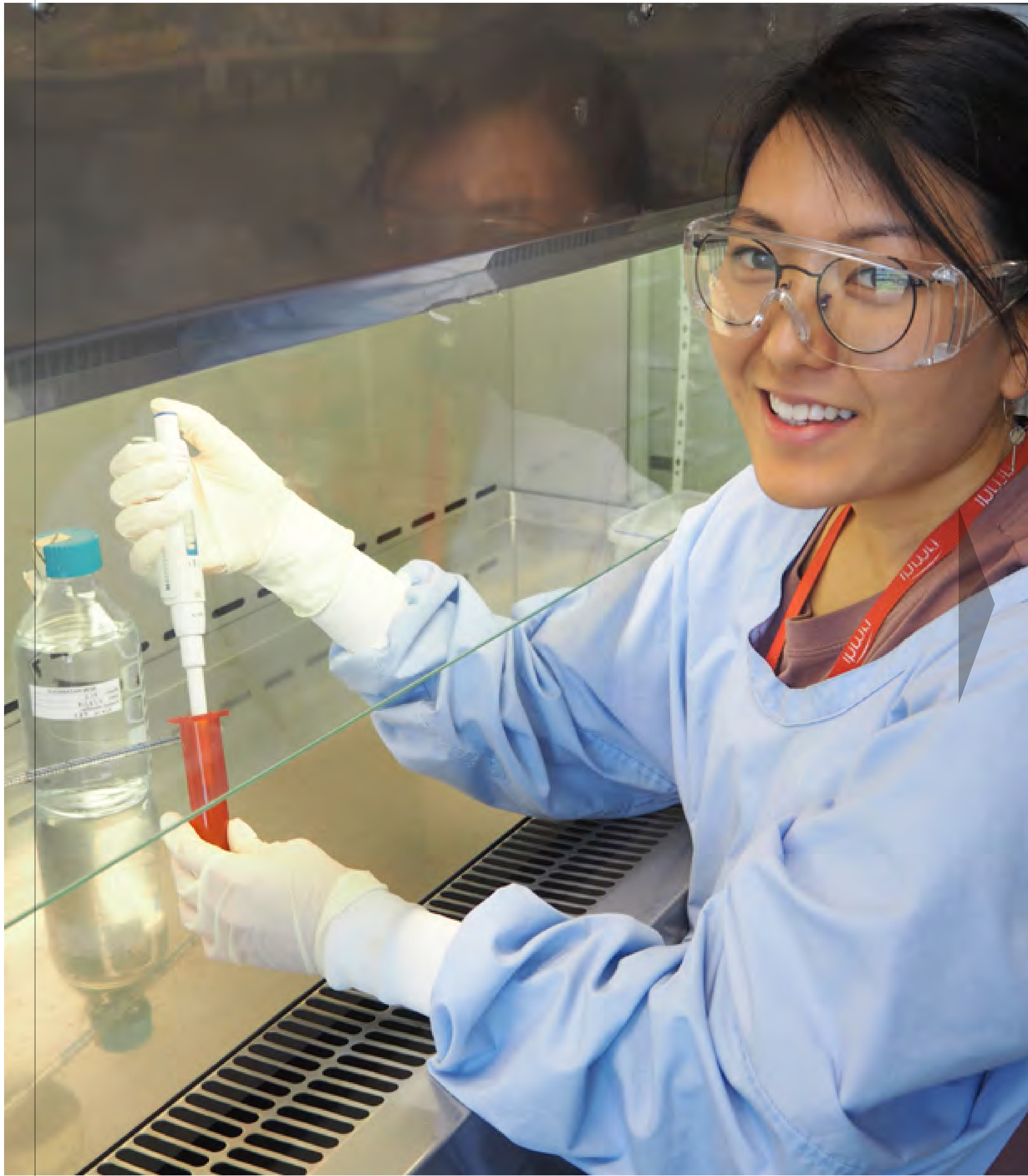
The possibility of controlled protein delivery, electrophoresis isolation (separation of charged molecules), and separation of biomolecules and bacteria cells has also been demonstrated.

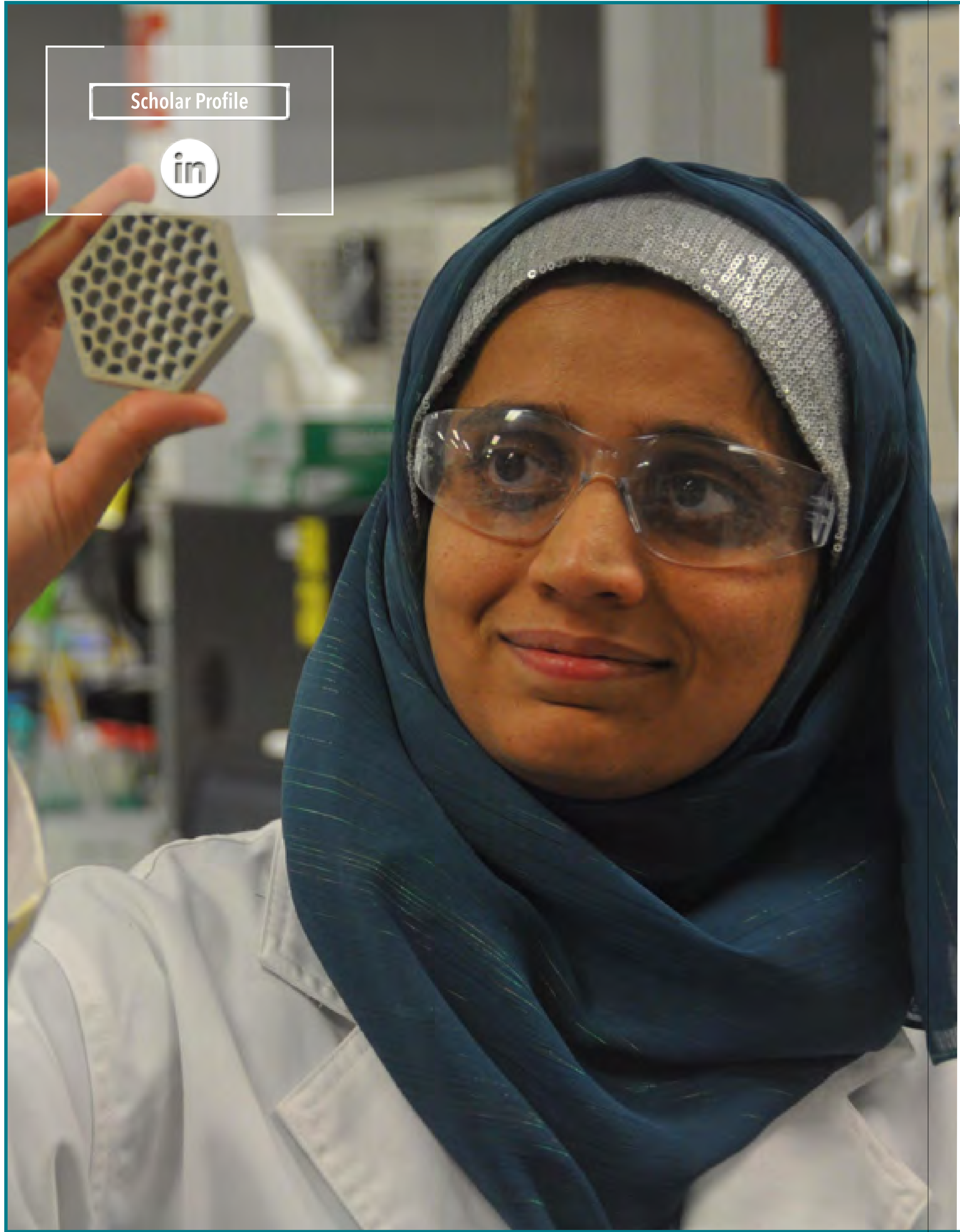
ACES affiliate and University of Wollongong PhD candidate Luciana Yumiko Daikuara, who worked on the project, said the team was very excited by their achievement.

"We were all buzzing when we sat back and realised what this potentially meant - this ability to separate targeted biomolecules from complex biological fluids using electric fields could become a new diagnostic tool, to be used in applications such as bioactive molecule delivery to soft tissue, a means of detecting bacteria in urine, and for protein separation," Luciana said.

In response to improving public health in developing countries with access to latest diagnostic technologies, the World Health Organisation has prioritised the development of targeted ASSURED diagnostic devices to the end user:

- **A – Affordable**
- **S – Sensitive**
- **S – Specific**
- **U – User-friendly**
- **R – Rapid and Robust**
- **E – Equipment Free**
- **D – Deliverable**





ACES RESEARCHER SPOTLIGHT

Dr Sidra Waheed – Electrofluidics and Diagnostics Theme (University of Tasmania)

Can you tell us a little bit about your background before you joined the ACES team?

I completed my Bachelor of Science (Honours), majoring in Chemistry, at Government College in Lahore, Pakistan. I then worked as a researcher at the University of Punjab, Pakistan where I was examining the development of desalination membranes for reverse osmosis.

After spending the past four years at the University of Tasmania, I'm excited to say I have finalised and submitted my PhD thesis.

What made you decide to get involved with the research at ACES?

There is a relative lack of printable materials with tailored functional properties, which really limits the applicability of three-dimensional (3D) printing.

My research is looking to develop composite functional 3D printable materials featuring improved thermal conductivity, electromechanical/chemical sensitivity, and mechanical strength. By enhancing these physico-chemical properties of composite materials we can increase the applicability of 3D printing technology.

When I started my PhD in 2015, 3D printing was really taking off as an enabling technology in materials science. I was curious to learn about 3D printing, and this spurred my passion to contribute towards the development and advancement of 3D printing technologies.

Working across disciplines with ACES and the Australian Centre for Research on Separation Science (ACROSS) has given me the opportunity to collaborate and further my research with a diverse group of experts.

I've heard you've achieved some pretty impressive milestones during your time in ACES. Can you tell us a little more about these?

I was thrilled to receive the European Materials Research Society (E-MRS) Young Scientist Award in 2018 at the E-MRS Spring meeting in Strasbourg, France, where I presented a paper titled 'Breaking barriers within 3D printing technology: Development of low cost 3D printable diamond composite'.

My Critical Review paper titled '3D printed microfluidic devices: enablers and barriers', published by the Royal Society of Chemistry in 2016 has also been cited 205 times to date – I'm told this is ACES' highest citing article published in the past three years, which is pretty exciting. I've had the amazing opportunity to witness the exponential growth of 3D printing technologies over the past few years, and I'm proud to have put all my research efforts towards being part of this evolution.

Access Sidra's Critical Review Paper here

What are the potential future real life benefits that could be developed from your research?

There is a general consensus among users that new print-compatible materials, including composite and functional materials, are required to expand the applicability of 3D printing. The fabrication of composites for 3D printing is quite challenging, as it requires tight control over the filler dispersion, distribution, orientation and connection.

My project is focused on overcoming these limitations by developing novel functional materials and making these materials 'processable' and compatible with 3D printing techniques.
The synthetic micro-diamond microfluidic chips I have developed using a 3D printed template to enhance the thermal conductivity of conventional polymers and ensure efficient heat dissipation offer real potential as a practical solution for the cooling of electrofluidic embedded electronics and mechanical-electronic micro-systems.

I have also developed synthetic diamond-containing filament for direct printing through a Fused Deposition Modelling (FDM) printer. As electronics have become smaller and more powerful, thermal management has become one of the key limiting factors in device performance. There is an increasing demand for thermally conductive but electrically insulating materials to assist in the cooling of miniaturised microelectronic devices with portable/wearable medical devices.

> “The future is bright, and we’re thrilled to be part of the movement towards a renewable energy revolution.

Synthetic Energy Systems

GREEN AMMONIA: SECURING FOOD AND ENERGY SUPPLIES FOR THE FUTURE

In Australia, we love our food. We spend over $115 billion on food production and close to $100 billion on household food consumption annually – that’s a lot of tomatoes. The world’s ability to mass produce food can be contributed to one little formula – NH_3 – ammonia.

Ammonia is one of the most widely produced chemicals worldwide, mainly used in agriculture as fertiliser, and has transformed global food production in order to meet the needs of our growing world population.

However, the current production of ammonia requires high temperatures and pressures, a large amount of fossil fuels and results in a significant amount of pollution. In fact, ammonia manufacturing for fertiliser is responsible for approximately two per cent of global carbon dioxide emissions. When you consider our population will grow by 2 billion people by 2050, we’re going to need a lot more fertiliser to meet the rising demand for food production. More importantly, we’re going to need a sustainable method to produce ammonia.

That’s where ACES researchers come in. Under the direction of ACES Chief Investigator **Professor Doug MacFarlane**, the team is investigating a new application of ‘ionic liquids’ – salts that are liquid at room temperature – that is poised to have a significant impact on the renewable energy industry.

Listen to Doug’s interview on ionic liquids here

“We are pioneering broad new families of liquid salts that are very effective in allowing us to produce ammonia from the nitrogen in the air around us,” Doug said.
“We have an opportunity to efficiently and cleanly produce ammonia using renewable energy at room temperature, and reduce the significant environmental footprint of the ammonia industry.”

For Doug, sustainable ammonia opens up enormous opportunities for Australia beyond supporting the fertiliser industry, and could put Australia at the forefront of the renewable energy industry in the current technological boom.

Hear more about sustainable ammonia here

“Australia is a huge untapped resource when it comes to renewable energy. The energy efficiency of a standard solar cell in north-west Australia is three times higher than in Europe or Asia. You could cover a 250km x 250km area in central Australia (smaller than Australia’s largest five cattle stations combined) with standard solar panels and generate the electricity supply of the whole world,” Doug explains.

“However, we are currently limited in our ability to utilise this renewable energy for export, as international markets are too far away to reach with high voltage cables. Instead, we need to be able to turn this energy into a transportable fuel.”

Hydrogen (H_2) is commonly seen as the most obvious choice for a simple, renewable fuel that can be exported. However, liquefying hydrogen for transport is no easy task. Temperatures below

-253°C are required, an effort that consumes close to one third of the energy provided by the hydrogen being transported. Put simply, this process is inefficient.

A prospective alternative fuel for export is ammonia as it is easily liquefied simply by increasing the pressure to around 10 atmospheres, a much more moderate process. Ammonia is therefore primed to become a valuable, energy dense commodity that can be utilised by power plants to generate electricity or 'cracked' into hydrogen, which can be used to power fuel cell cars, all while generating zero emissions.

This is where the significance of Doug's work really makes its mark. There is a keen focus from researchers, industry and government on the cleanest, most efficient processes to generate ammonia from the nitrogen in the air and water around us, including the ACES team's use of ionic liquids. There is such interest in the potential of this technology, that Doug and his team received a grant of over $900,000 in 2018 from the Australian Government's **Australian Renewable Energy Agency (ARENA)** to further this research.

The possibility of renewable ammonia serving as a green fuel and becoming Australia's future energy export is very real.

"Our work to develop new technologies for storing renewables as transportable material is an important step in transforming Australia as a sustainable energy exporter, which we believe will help to move us away from our reliance on fossil fuels towards renewables," Doug said.

"In the short term we will be focused on scaling up and optimising our ammonia synthesis technology, to eventually define a large scale, practical option for the export of renewables and move this innovative technology towards commercialisation. "The future is bright, and we're thrilled to be part of the movement towards a renewable energy revolution."

BEYOND LITHIUM: THE QUEST FOR A BETTER BATTERY

Rechargeable lithium-ion batteries were a revolution for their time. Thanks to this relatively small, lightweight vessel packed full of energy, our lives quickly became filled with technologies that provided flexibility, entertainment and a world of possibility, from smartphones and other portable electronic devices, to household appliances, through to electric cars.

However, like the telegram, the typewriter, floppy disks, and the VCR, it is expected that the lithium battery will be superseded in the near future, and ACES researchers at our Deakin University node are at the forefront of advancing new technologies to replace them with a more sustainable alternative.

While groundbreaking at the time, the rapid development of advanced technologies has exposed the limitations of lithium ion batteries. These limitations include: safety issues (remember the exploding batteries in some mobile phones that caused massive recalls in 2016?); the use of critical materials such as lithium and cobalt that are only available in a few parts of the world and often mined using environmentally-harmful and ethically-concerning techniques; and constraints in the maximum energy density of lithium ion batteries and associated charging technologies. The search is now on for a better battery technology that is safer, cheaper and longer lasting. For ACES Associate Director and Chief Investigator **Maria Forsyth**, there are a number of exciting options researchers at the Centre's Deakin node are exploring to create a more sustainable battery future.

"Our team is conducting world class research in a number of areas that can offer specific, tailored battery solutions to meet industry needs, from small personal device items, to powering vehicles, and generating sustainable electricity supply," Maria said.

"With established local and international industry collaborations, we're quickly moving towards exciting new energy technologies that can address major challenges at the heart of this new world of energy provision and storage requirements."

Carbon-Based Technologies

A key focus for the ACES team is determining an alternative chemistry to develop metal air batteries using materials such as magnesium, zinc and sodium. Metal-air batteries typically consist of a metallic anode and a porous cathode that allows oxygen from the atmosphere to be used as a reactant. Researchers across ACES are collaborating on this project to synthesise carbon-based materials such as nanofibres, nanotubes and graphene to use in our devices. ACES Chief Investigator **Professor Patrick Howlett** said the team was focused on metal-air batteries given they have an energy density that is much higher than traditional lithium ion batteries, making them a prime candidate for use in electric vehicle technology.

"The metal-air batteries being developed at ACES use energy dense metal negative electrodes with an ionic liquid electrolyte, and the oxygen in the air around us is then used for the positive electrode reaction," Patrick said.

"This novel system means our batteries have less volume, meaning they have less weight, which considerably improves performance – this development is especially exciting for the electric car industry, where drivers have rightly been demanding longer driving ranges and faster charging times."

The team has established a number of collaborative agreements with major automotive manufacturers, including Toyota, further confirming that the work the ACES team is developing in their labs has the potential to be a game changer in the electric car industry.

Sodium-Ion Batteries

The ACES team is also investigating a sodium-ion breakthrough, which promises some attractive technology opportunities in future smart energy grids to ensure reliability, availability and efficiency in our energy systems.

Sodium-ion batteries have a lot going for them – there is an abundance of sodium in the natural environment, and sodium shares a number of similar properties to lithium. Sodium-ion batteries promise to be cheaper and safer than their lithium-ion counterparts, and are also capable of charging and discharging at higher rates. Researchers at ACES are working on designing a sodium-ion battery that is synthesised from low-cost, abundant materials with secure supply chains that can be 'dropped in' to systems currently using lithium-ion without the need for a complete overhaul.

Thermocells

On another front, our researchers are examining the exciting opportunities offered by 'thermocells', which can continuously produce electricity – no charging required – without harmful carbon dioxide emissions.

Immense amounts of low-grade waste heat (temperatures below 130°C) are emitted from vehicles, domestic and industrial infrastructure and appliances, and even the human body. The thermocell technologies being developed by the ACES team can harness this currently untapped source of sustainable energy. Traditionally, small semi-conductor based thermoelectric devices can be inefficient and expensive when attempting to utilise waste heat at moderate temperatures.

ACES Chief Investigator **Professor Jennifer Pringle** said the thermal energy harvesting group is looking to advance this highly topical area of research, including the potential to make larger scale, lower cost devices for harvesting low-grade waste heat.

"Our team is developing innovative materials and devices that will allow you to harvest waste heat from your body, your car, your home, and your business to produce electricity," Jenny said.

"The future opportunities to utilise this technology are boundless – from decreasing your electricity bill, to powering small portable electronics while on the move."

A thermocell consists of two electrodes in contact with an electrolyte, much like a traditional battery. The advantage of the thermocell is that it never needs to be recharged – energy conversion is instant and continuous as long as one electrode is heated and the other is kept cold (e.g. cooled by air). The thermocells developed at Deakin are unique, as they contain electrolytes that are non-volatile, non-flammable, flexible and redox active solids – this means they will not evaporate or leak from the device. Jenny explained the unique characteristics of these thermocells make them suitable for a plethora of applications to convert waste heat to electricity.

Access thermocells paper in Sustainable Energy & Fuels here

"Our thermocell technology utilises the benefits of ionic-liquid based redox electrolytes – salts that are liquid at room temperature – which are ideal for harvesting waste heat below 150°C," Jenny said.

"The gelled electrolyte films are ideal for us to use in pouch-cell designs, for flexible and leak-free devices."

Competitive thermal energy harvesting technologies are primarily directed at harvesting higher temperatures of waste heat (over 150°C). The thermocells being developed by ACES researchers, however, could be wrapped around industrial or domestic hot pipes to provide an energy contribution to offset the energy demands or houses and buildings without using turbines or pumps.

The team is also developing a range of water-based, quasi-solid redox active electrolytes, that are thin, flexible and leak-free, making them ideal for more ambient temperature applications such as small portable electronic devices or wearable (such as smart watches or sensors). These thermocells would reduce the need for frequent charging and could ultimately power the device directly.

Thermocell generators for E-skins

A highly promising application of thermocells is in the area of electronic skins (E-skins). E-skins are artificial skin-type electronic devices that can mimic the sensory and self-healing functionalities of natural skin, monitor vital signs, and deliver diagnosis remotely.

As the aging population increases, the global market for E-skin devices and chips is anticipated to reach $1.7 Billion by 2025, as the technology holds great promise for applications in health monitoring systems, limb prostheses, soft robotics and artificial intelligence.

To date, the lack of ultrathin, stretchable and reliable power sources has dramatically hindered the commercial application of E-skins. To combat these limitations, ACES researchers at the University of Wollongong are working towards thermocell (TE) generators to power the miniaturised sensors and circuits in E-skins.

These thermocells would utilise bioprinting with customised bioinks on a soft biocompatible substrate with pre-patterned electrodes that allow the production of a flexible, ultrathin generator that can conform well to the skin to enable seamless integration into existing E-skins.

ACES CI **Professor Jun Chen** said the team's work towards creating a flexible, effective TE generator to power E-skins is a step in the right direction towards the field of health monitoring and diagnosis.

"Our proposal to use ink-based materials allows the integration of power supply and energy storage in a cost-effective way while ensuring the ink parameters can be carefully controlled, providing solutions to some of the current barriers in E-skin devices in terms of flexibility, material degradation and low-power generation," Jun said.

BatTRI-Hub

The advancement of these energy storage technologies towards refinement and commercialisation is greatly buoyed by the recent commissioning of the **Battery Technology Research and Innovation Hub**, known as BatTRI-Hub, located at the Deakin campus. Led by ACES Associate Director Professor Maria Forsyth, the Hub capitalises on the electromaterials research expertise developed at ACES to further develop this next generation of battery technologies, in collaboration with the polymer research strengths of CSIRO.

Maria said the BatTRI-Hub creates the ideal platform to prototype novel energy storage devices with design optimisation and operational flexibility to suit the modern world's growing technological needs.

"The Hub will enable the tailoring of research programs to meet specific industry needs and consumer demands as batteries continue to evolve from small personal use items, to powering our modes of transport and our electricity supply," Maria said.

The Hub is fast becoming a centre for all kinds of industry engagement ranging from chemical companies, through to battery manufacturers and energy providers. A number of businesses and research groups have come on board to partner with the world class researchers on offer at the BatTRI-Hub, including Toyota, AusNet Services, Boron Molecular, Wilsons and Calix.

These local and international partnerships will allow for accelerated progression towards solutions for targeted industry challenges. Maria believes the team is on the cusp of having the fundamental research being translated into successful, useable technology for consumers.

"We are in exciting times, and the ACES team is certainly leading the way for 'what's possible' in terms of sustainable power and energy storage. Our ability to power the world using clean energy is real and it's getting closer."

ACES RESEARCHER SPOTLIGHT

Dr Ben Noble – Synthetic Energy Systems, Synthetic Biosystems, Electromaterials Themes (Australian National University)

You've come through the ranks under the guidance of ACES CI Professor Michelle Coote. Can you tell us a little bit about your research journey?

I've been fortunate to complete both my Honours project and PhD with Prof Coote. I completed my PhD in 2016 on stereochemistry in radical polymerisation, and then took on a postdoctoral position with Michelle's Computer Aided Chemical Design Group. I specialise in computational chemistry, which is a branch of chemistry that uses computer simulation to determine certain chemical outcomes. My research focus falls into two main categories. The first explores the mechanisms of photochemical reactions to assist with molecule and polymer synthesis, which can be quite helpful in terms of effective drug delivery. The second involves using computational chemistry to study the degradation of the molecule alkoxyamine, which is potentially interesting for devices like batteries and capacitors from an energy storage perspective.

It sounds like you're covering two incredibly different fields – or are they really not so dissimilar?

Overall, I'm trying to better understand photochemical reactions to better assist in making molecular chains. Firstly, there's a whole class of photochemical reactions that are quite important in making specific architectures. So, you might take polymer chains and then graft other polymers onto them to construct molecules for drug delivery.

Lots of 3D printers operate on a UV wave length, and the treatment of your cells are dictated by the inherent properties of the photo initiator you're using – in a way you're 'sunburning' your cells before you start laying them down, which isn't ideal! The preferred approach would be to have more control over these reactions. You want to be able to put these molecules together in a really organised way and govern the structure you end up with. Understanding this process at a molecular level will assist with this desired control.

I'm also focusing on a particular type of organic molecule called alkoxyamine. Some alkoxyamines degrade when you pass a current through the solution and others don't, so we've been trying to understand why this is. Alkoxyamines that don't degrade hold some interesting potential for devices like batteries and capacitors from an energy storage perspective. Likewise, the alkoxyamine molecules that degrade are undergoing a chemical change and we'd like to better understand this process so we can harness this for certain types of applications. So far, we've found that the environment that the alkoxyamine is in also influences the breakdown, not just the molecule itself.

What do you think the biggest challenge is in terms of the work you do?

I think one of the big issues or misconceptions with computational techniques is the computer does all the work for you – that's not the case – we have to know our chemistry to be able to know what we're trying to work out. We also need to be careful of bias. When we work with collaborators who are really excited with a particular result, we need to make sure we don't bias the result by trying to prove that the experiment is seeing what it's seeing for the reason that the collaborator thinks.

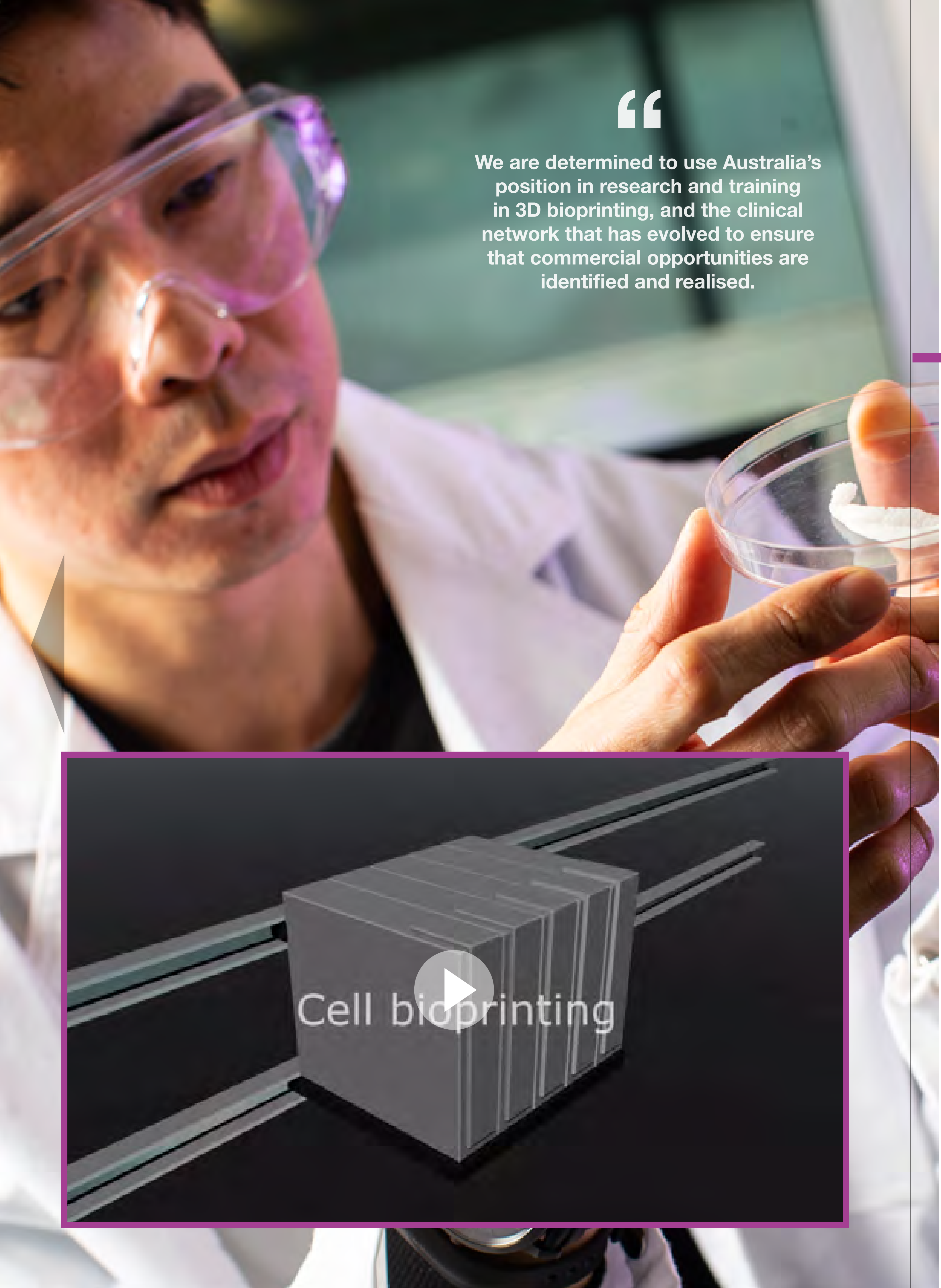
What we do is model very, very specific reactions – it's hard to overstate how specific it is.

What about the most rewarding part of your work?

It's going to sound really cheesy, but I think one of the most rewarding parts of computational work is when you determine why something isn't working as you thought it would. You often take a look at an experimental mechanism and it looks reasonable however the calculations will say the result just isn't possible, and then you'll think of an alternative mechanism.

I think this is really rewarding because it really highlights where computational chemistry makes such a valuable contribution – of course the experimental result is a result and yes, that result is true and can be published, however it's the explanation that is critical. If this understanding is not quite right, it can affect how people approach new projects and use this research.

If you want to get the rational design for your research – that is, not by accident – computational chemistry plays such an important role.



> We are determined to use Australia's position in research and training in 3D bioprinting, and the clinical network that has evolved to ensure that commercial opportunities are identified and realised.

Synthetic Biosystems

3D BIOPRINTING: THE REALITY IS CLOSER THAN YOU THINK

Picture this. Your knees have been feeling stiff and sore, and a trip to your GP reveals you have arthritis. The cartilage between your joints is deteriorating and causing you significant pain. So, you visit your local hospital for minor surgery with a novel device where the defects in your knee are 'coloured in' using ink made out of your own stem cells.

Before you know it, these cells have become functioning tissue and you're back out on the squash court, or the footy field, or the dancing stage.

Science fiction? Nope. This scenario is not as far-fetched as it may have once sounded. Around the globe, there is a growing community of surgeons, biomedical engineers, biologists, chemists and engineers working side by side to turn the concept of 3D bioprinting into a real world, effective treatment for significant clinical challenges.

Researchers across ACES are part of this growing industry, with the team focused on developing tailor made therapies utilising customised bioprinters and bioinks to treat the medical challenge at hand.

ACES Director Professor Gordon Wallace said rapid advances have been made possible through the integration of fundamental materials science research with cutting edge approaches to fabrication, including 3D printing.

"At ACES, we're working tirelessly to create 'smart devices' that utilise the advanced materials we make in our laboratories to create new health solutions to improve people's lives," Gordon said.

"Our approach focuses on developing clinical solutions for significant medical issues by identifying and customising materials and fabrication protocols, and delivering 3D printing solutions for clinical environments.

"This includes utilising commercially available 3D printers to design and develop customised technologies; customised bioink formulations to deliver viable cells where they can proliferate and differentiate according to specific requirements; and ensuring the end product is arranged for optimal performance, including the correct arrangement of structural and bioactive materials."

Customised Bioprinters

The ACES team at the University of Wollongong is building customised 3D bioprinters to address clinically defined needs. Bespoke hardware and control software allow biologically relevant structures to be printed with precisely distributed cells, mechanical reinforcements and supportive growth factors throughout.

Read more about the future of 3D bioprinting here

The printing systems are also tailored for compatibility with direct use in clinical environments.

Customised Bioinks

The ink formulation that goes into a bioprinter is as important as the printer itself. Each of the novel hardware applications developed by ACES utilises customised, sophisticated bioink formulations that provide structural support and protect living human cells.

This customised approach allows cells to proliferate and differentiate according to the specific requirements of the treatment, including the correct arrangement of structural and bioactive materials. The laboratories at ACES' headquarters at the University of Wollongong are fitted out with facilities and expertise that allow for the synthesis of materials for bioinks to enable the supply of a range of small to medium scale quantities of bioinks.

The intricate reactors are capable of synthesising a range of bioinks for use in applications such as cartilage regeneration, nerve regeneration, and islet cell replacements.

The ACES team is always on the lookout for new innovative, affordable, and effective biomaterials that can aid the 3D bioprinting field.

A collaboration with Dr Pia Winberg, Director and Chief Scientist of **Venus Shell Systems**, explores using the unique qualities of Australian seaweed as a potential biomaterial.

The gel-like glycan polysaccharides in the seaweed mimic human connective tissue, which could be used in 3D printing to reconstruct soft tissue for functions such as printing cartilage and wound healing.

Read more about Australian seaweed here

The Axcelda Pen – combining science, engineering and medicine to prevent osteoporosis

In partnership with **Professor Peter Choong** at St Vincent's Hospital Melbourne, ACES has developed a customised bioink and handheld printing device that can be used in surgery to repair damaged cartilage. The Axcelda Pen is a handheld 3D printer pen used to 'draw' human stem cells and growth factors in freeform patterns to the site of injury. This device gives surgeons greater control over where the cells are deposited when treating joint repairs, reduces the time a patient is in surgery, and is less invasive than current treatments.

Read more about the research behind the Axcelda Pen in Biofabrication here

The collaboration has brought together scientists, engineers and clinicians, as well as the science of stem cells, polymer chemistry and 3D bioprinting to help surgeons design and personalise a solution for osteoarthritis. Director of Orthopaedics and Professor of Surgery at St Vincent's Melbourne Hospital, Professor Peter Choong said the Axcelda Pen has the ability to make a material difference in preventing osteoarthritis and potentially a variety of other clinical situations. To date, no clinical strategies are capable of consistently reproducing normal hyaline cartilage, which has the cellular and mechanical characteristics to sustain the everyday demands of shear and compression.

"This technology is a game-changer, and we are excited by the opportunity to prevent the onset of osteoarthritis in patients by using 3D technology to print live cells to repair damaged cartilage. The development of this type of technology is only possible with scientists and clinicians working together to identify the problem and develop a solution," Prof Choong said.

The Axcelda Pen project was one of 11 projects selected in 2018 for the Australian Government's $35 Million BioMedTech Horizons program, as well as being named as a finalist for the prestigious 2017 and 2018 Australian Museum Eureka Prizes. The team is continuing its work to refine the technology for eventual commercialisation including the refinement of hardware for manufacturing, large animal trials, and the processing of stem cell inks.

3D Alek – a customised 3D bioprinter to treat microtia across the globe

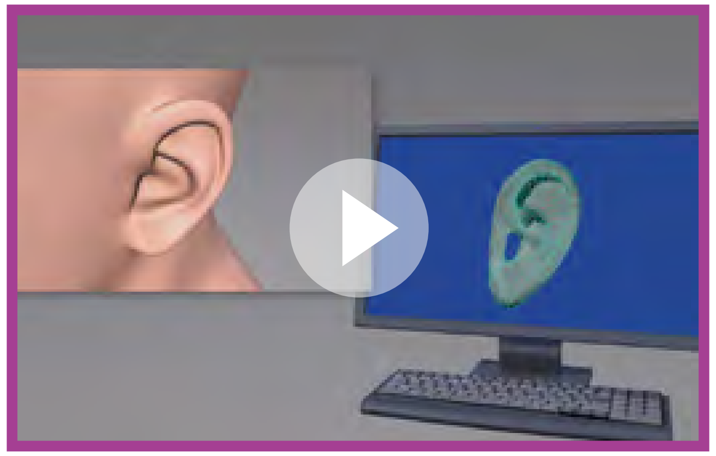
ACES has partnered with **Associate Professor Payal Mukherjee**, Ear, Nose and Throat (ENT) Surgeon from Royal Prince Alfred Hospital in Sydney to design a 3D printer that can treat microtia, a congenital deformity where the external ear is underdeveloped.

The ACES team has built a customised multi-materials biofabrication 3D printer as well as the required bioinks to support this project which aims to regenerate cartilage for use in reconstructive ear surgery. A/Prof Mukherjee said she was thrilled to be working with ACES researchers to develop a solution to combat microtia that is individualised to match the patient's own anatomy.

Learn more about combating microtia here

"Treatment of this particular ear deformity is demanding because the outer ear is an extremely complex 3D shape, not only in length and breadth, but also in height and projection from the skull," A/Prof Mukherjee said.

"This is where bioprinting is an extremely exciting avenue, as it allows an ear graft to be designed and customised to the patient's own face using the patient's own natural tissue, resulting in reduced operating time and improved cosmetic outcome, and avoids the current complication of requiring a donor site for cartilage, usually from the patient's rib cage."



There is also work to adapt this technology so it can be translated on a global scale affordably and efficiently to assist with the treatment of microtia across the world, especially in developing countries.

The iFix Pen – a 3D printer set to revolutionise corneal health

In conjunction with **Professor Gerard Sutton** at the Lions NSW Eye Bank and Sydney University, ACES researchers are working to develop a novel medical treatment technology that incorporates 3D printing to repair corneal ulcerations. The iFix system distributes a 3D-printed structure directly onto the eye, utilising the iFix Pen developed by ACES researchers at the University of Wollongong. The iFix Pen is a handheld 3D-printing device that delivers a specialised bioink formulation to the eye defect with high accuracy.

Professor Gerard Sutton said working with ACES researchers was helping to fast track the novel device into a commercial product.

"Corneal disease is the third most common cause of blindness worldwide, and corneal ulceration accounts for 55,000 presentations to hospital each year in Australia," Prof Sutton said.

"Our iFix system will provide easy-to-use technology to repair corneal ulcerations with precision, while addressing current issues associated with corneal repair including pain relief, infection and the development of scar tissue, and has a low risk of error in terms of compromising sight."

The team received $1.15 Million in funding from the NSW Government's 2018 NSW Medical Devices Fund to further develop its iFix system.

3D PICT – One step closer to new therapy to treat diabetes

3D-bioprinted shells could be the key to successfully transplanting islet cells to treat Type 1 diabetes, according to ACES researchers. The team at the University of Wollongong in conjunction with Royal Adelaide Hospital (RAH) have demonstrated a breakthrough in 3D bioprinting insulin-producing islet cells to overcome some of the critical limitations in current cell transplantation.

While pancreatic islet cell transplantations have become a promising treatment for Type 1 diabetes, there can be poor cell survival rates due to insufficient revascularisation of cells post-transplantation. This new approach has the potential to restore circulation to the area more effectively and to protect the implanted material from immune reactions.

Central to this work are the cutting-edge biomedical printing device, 3D PICT, and customised bioink formulation both designed and built by ACES researchers. The customised 3D bioprinter and bioink has allowed the team at RAH under the guidance of **Professor Toby Coates** to fabricate with precise control 3D islet-containing structures with a unique shell layer. This 'Trojan horse' style printing process allows the islets to be delivered into the body in a way that protects and maintains the viability of the cells.

Read more about developing the 3D PICT here

Toby said this breakthrough research could revolutionise treatment for people living with Type 1 Diabetes.

"The novel bioprinting process offered with the 3D PICT and designer bioink formulation allows us to use the patient's own cells to create the 3D printed islet structure, meaning we are minimising the distance between each islet to ensure better circulation of nutrients and oxygen, and ultimately reducing the likelihood of rejection in the person's body," Prof Coates said.

"The next step is to conduct in-depth animal trials, as well as further optimise the bioink formulation to ensure the islets are preserved after encapsulation and transplantation."

TRICEP strengthening 3D bioprinting in Australia

Just across the road from ACES headquarters at the University of Wollongong is a building filled with the latest advanced 3D bioprinting technologies. The initiative – known as **TRICEP (Translational Research Initiative for Cellular Engineering and Printing)** – draws on the expertise and facilities available within ACES and the Australian National Fabrication Facility (ANFF) Materials Node to further unlock breakthroughs in the treatment of significant medical conditions.

ACES and ANFF Materials Node Director Professor Gordon Wallace said TRICEP offers Small Medium Enterprises (SMEs), research institutions and industry the opportunity to partner with leading researchers to develop and commercialise 3D bioprinting technologies for use in the medical industry to combat significant clinical challenges.

"The TRICEP team has a strong track record of identifying and customising materials and fabrication protocols to deliver 3D bioprinting solutions for real world clinical problems," Gordon said.

"Drawing on the fundamental research and expansive clinical network of ACES means there is a strong in-house ability to develop both customised hardware and bioinks to assist companies create a complete end product that is tailor-made to combat a specific medical challenge."

3D Bioprinting in Australia – we truly are connected

Gordon strongly believes Australia's integrated activities in 3D bioprinting enables organisations like ACES to traverse the 'ideas to industries' pipeline.

"With our activities in ACES and ANFF Materials Node, our strong national clinical network is growing globally, with numerous active international collaborations. Just recently, we signed a Memorandum of Understanding with the Korean Society of 3D Printing in Medicine," Gordon said.

"We also have the advantage of experience with regulatory, ethical and community engagement activities, working alongside those with a flair for development of new commercial models to ensure research activities are sustainable. This is a rare combination of skills integrated into a team to ensure delivery of real medical solutions."

"We are determined to use Australia's position in research and training in 3D bioprinting, and the clinical network that has evolved to ensure that commercial opportunities are identified and realised."

PERSONAL EPILEPSY ANALYSIS FOR EFFECTIVE TREATMENT

Epilepsy causes uncontrollable, spontaneous, recurrent seizes in 1 to 2 per cent of the global population. Sadly, five in every thousand people with epilepsy die unexpectedly each year, and many more are seriously injured as a result of their seizures. There are a range of epilepsy drugs available, however when a patient presents with epilepsy, it is difficult to determine the exact drugs required to treat their specific condition. Current systems rely on trial and error to determine which drug is going to work best for a particular patient, which can take years to finalise. Often, doctors find medications are only partially effective or that a patient's therapeutic drug regime needs to be modified due to high degrees of acquired tolerance or because of a range of unacceptable side effects.

The ACES Synthetic Biosystems team at the University of Melbourne is working to overcome this challenge through a personalised neuro-modelling drug analysis system to quickly and effectively determine the best treatment for a patient's particular type of epilepsy. The *in vitro* system converts a patient's stem cells from a blood sample into 3D neural tissues. Researchers then induce epileptic symptoms into those 3D neural tissues, and record their electrical activity (as epilepsy is excessive electrical activity of the body's cell network). The personalised epilepsy drug analysis system would allow clinicians to examine this sample of the patient's 3D neural tissue to diagnose the nature of the patient's epilepsy and determine the optimal drug regime for an individual approach to treatment.

ACES researchers have been able to show for the first time that the cellular activity of 3D neural cultures when induced with epilepsy look very much like activity in the brain. This system provides a better neurological model than existing neural cultures, and forms the basis for establishing effective personalised drug management for existing neurological conditions. The team is now utilising this technique to examine cells from patients who suffer from epilepsy to further develop a clinical tool for drug selection personalised to each patient.

ENABLING FUNCTION WITH NEURALLY-DRIVEN PROSTHETICS

Did you know the cost of limb amputations, and access to remedial therapies continues to rise each year? In 2009, the annual cost of limb amputations to the US economy was close to US$8.3 Billion. In Australia, diabetes-related amputations alone number more than 4,400 per annum, and cost the economy nearly AU$875 Million each year. In order to provide a better quality of life after amputation, the field of advanced prosthetics is working towards the development of intuitive-controlled prosthetic devices. This type of device would allow the prosthetic to be controlled by the same brain region that controls our other limbs. To achieve such a prosthesis, an interface needs to be developed that effectively understands how a person's nerves and muscles interact so the prosthesis is controlled by a person's own nervous system without direct thought or concentration.

As part of this work, the ACES Synthetic Biosystems team at the University of Melbourne has developed 3D muscle constructs connected to nerve endings to develop a better understanding of the connection and interaction between nerves and muscles. The 3D printed muscle models allow researchers to investigate and better understand how nerves and muscles interact and operate by recording electrical activity from muscle when nerves are stimulated. By recording electrical activity from the muscle rather than the nerve, researchers avoid damaging delicate nerves with electrodes, making the data far more reliable.

By optimising the connection between the nerve and the 3D printed muscle, and recording this activity, the team can then work towards developing an algorithm that can effectively communicate between and utilise the electrical activity between the device and a person's nerves and muscles. This advance is allowing the expansion of further research between the ACES Synthetic Biosystems and Soft Robotics teams and collaborators at St Vincent's Hospital Melbourne and the University of Melbourne, who have developed a conceptual electronics/nervous system interface, the 'Electronics-Neural Adaptive Bionic Limb Electrode interface', or ENABLE-i.

The interface delivers motor neuronal signals to an electrode array that can be embedded within a prosthetic device. To date, the team has been able to process electrophysiological recordings to drive finger movement on a robotic hand. This approach differs to other approaches in robotic research as it features a strong reliance on novel biomaterials and tissue engineering techniques to assist with signalling and actuation between humans and prosthetics. The interface will also potentially provide opportunity beyond its current application of prosthetic limb control, such as mechanical actuator systems to restore lost functionality due to injury or disease, and even aging, particularly sphincter control for incontinence and oesophageal motility restoration for swallowing.

BIOELECTRICITY: THE NEW FRONTIER IN TREATING DISEASE

Imagine a world where some of our most common illnesses are treated without drugs. This is the reality ACES scientists are working towards with their latest 'electrifying' research.

It's safe to say that most of us have visited the chemist at one time or another to pick up a prescription or some over-the-counter relief when we're feeling lousy. From winter colds and migraines that simply won't go away, through to more chronic conditions such as epilepsy, heart disease, and diabetes, pharmaceutical drugs play a significant role in our ability to tackle illness and promote wellbeing.

Modern pharmaceuticals are a part of our society in a big way. In 2015-2016, Australia spent $20.8 Billion on medicines (Australian Institute of Health and Welfare), including prescriptions and over-the-counter treatments. But have you ever considered a world where chronic illnesses can be treated without a reliance on drugs?

A world without drugs?

"We know that while pharmaceutical drugs have revolutionised the treatment of a multitude of conditions, we also know that there are definite side effects, as we can't control or limit the delivery of the drug to a specific area – we flood the body," says Professor Gordon Wallace.

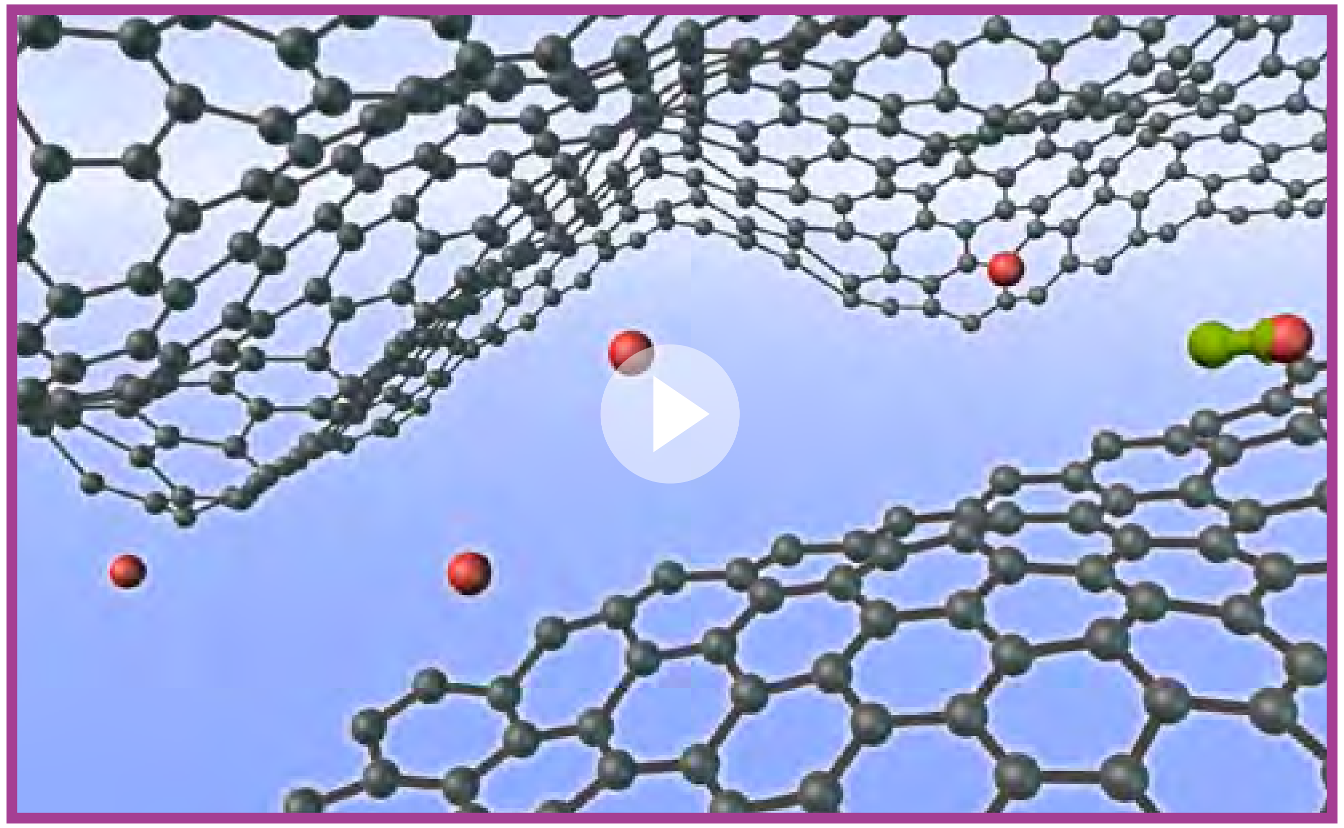
"We have now taken our research into the world of bioelectricity with the plan to utilise our new material developments and 3D bioprinting technologies to develop structures that can monitor, and restore function in neural tissues. Our ability to communicate with stem cells through electrical stimulation can also control their subsequent development."

Breaking the bounds of stem cell research

"We have been working for a number of years at ACES on using electricity to produce three-dimensional human neural tissues in the laboratory," explains ACES CI A/ Prof Jeremy Crook.

A human body has many different types of cells, and each set of cells has a job to do – think blood cells, muscle cells, fat cells, neural cells… Stem cells, however, are cells that do not have specific roles but can transform into more specialised cells that are required by the body. The ACES team is investigating using electrical stimulation to influence cell

Read more about this exciting research here



behaviour as a way to treat traumatic brain injuries and neurological disorders such as epilepsy and Parkinson's disease.

"Our bodies are naturally bioelectric, with organs and component tissues operating electrically for normal physiological function, including during development and healing following injury," Jeremy said.

Bioelectricity is used by our cells to regulate their function. In neural tissues, bioelectricity is generated so that cells can communicate with one another by impulses along nerve fibres. Prompted by the body's natural electricity, The team demonstrated the ability to sustain stem cells with electrical stimulation in 3D and accelerate their differentiation into excitable nerve cells with specialised connections. An additional important discovery was an increased responsiveness of nerve cells to drug treatment.

Learn more about this research in Advanced Healthcare Materials

"To date, research and development of cell culture has largely relied upon elementary 2D methods of cell culture, which are not representative of actual cell environments within tissues and organs of the human body," Jeremy said.

This new platform integrates biologically relevant human cell lines with advanced techniques for 3D tissue engineering and 3D electrical stimulation that mimics cell culture that better represents human cell growth and tissue outside the human body. The platform offers a number of exciting uses in both research and translation, including modelling tissue development, function, dysfunction, and pharmaceuticals responsivity, as well as electroceuticals and regenerative medicine.

"Going forward, our work could assist in the treatment of a multitude of conditions including neurological disorders such as epilepsy, schizophrenia, and Parkinson's disease to name a few, as well as tackling the current shortage of donor tissues for vital replacement therapies following trauma and disease," Jeremy said.

"We also have the potential to develop accurate predictors of therapeutic effects such as medicines by generating diseases and healthy tissues to replicate as closely as possible the targeted human condition.

We could also stimulate the cells in the central nervous system in 3D with both wired and wireless cell and tissue stimulation systems with the potential to be implanted and activated using low-invasive means."

This work has been nationally recognised, with the ACES team taking out the Frontiers Research Award at the 2019 Research Australia Health and Medical Research Awards.

Read about our Research Australia accolade here

Spinning medical gold

The ACES team is always thinking one step ahead, into how to move applications from the bench to the clinic. A key focus for the group is electroceuticals, which has become a hot topic of research in recent years, as it focuses on creating treatments with minimal invasion and side effects. Researchers are working towards the ability to administer electroceuticals (electrical impulses) that target specific neural circuits in body tissues and organs affected by an illness to improve performance.

Two birds, one stone

One of the main limitations in electroceutical research to date has been the fabrication of suitable implantable electrodes. Currently, electrodes are created using everyday materials such as metal, making them inflexible, potentially damaging to the nervous system, and limiting the effectiveness of electrical communication with the nerve and overall mapping of the body's neural circuitry.
Enter the 'sutrode'. The sutrode combines the electrical properties of an electrode with the mechanical properties of the suture to produce a fibre that is ultrathin (half the diameter of a human hair), strong, flexible and maintains electrical properties. The fibres have demonstrated significantly improved electrochemical activity within nerves, and are stiff enough to penetrate soft nerve tissue, yet flexible enough to accommodate for micro-movements once implanted, giving surgeons the ability to communicate with the nervous system in an unprecedented way.

"The not-so-secret ingredient in the sutrode is graphene," Gordon said. "We know graphene has remarkable properties, and we've been working to develop chemistries to enable the creation of useful structures that retain its amazing mechanical, electrical and biological properties.

Professor Mario Romero-Ortega from the University of Texas at Dallas, who collaborates on the sutrode project with ACES, said the opportunities offered by the sutrode were ground-breaking.

"Our sutrode could be an ideal material for developing the next generation of neural stimulation that provide the opportunity to treat a range of diseases without drugs," Mario said.

"The strength and flexibility of the sutrode allow us to tie the device around incredibly small nerve bundles that then record and detect neuronal activity, giving us more effective communication from these individual nerve areas to then determine specific treatments for specific conditions."

ACES RESEARCHER SPOTLIGHT

Dr Lilith Caballero Aguilar – Synthetic Biosystems Theme (Swinburne University of Technology)

Dr Lilith Caballero Aguilar has completed her PhD at Swinburne University under the supervision of ACES CI Professor Simon Moulton. Lilith is investigating 3D printing of drug delivery systems working out of St Vincent's Hospital Melbourne's BioFab3D facility.

Read more about Lilith's time with ACES here

How did you come to be a part of the ACES team?

I did my undergraduate studies back in Mexico at the University of Yucatan in Physics Engineering, and then I completed my Masters in Biomedical Engineering at KULeven in Belgium.

I had the opportunity to take on a PhD at Swinburne to assist with the development of suitable drug-polymer materials that can be fabricated into degradable drug delivery systems using additive fabrication techniques for *in vivo* applications.

Find out more about what makes Lilith tick here

As part of my PhD I get to collaborate with researchers and surgeons at BioFab3D, which is Australia's first hospital-based biofabrication lab.

That's quite a mouthful! Can you tell us a bit more about this area of research?

In a nutshell, I'm working on developing effective drug delivery systems for the repair of tissue. Novel systems like the Biopen (read more about the Axcelda Pen on page 28) aim to regenerate cartilage by implanting materials, cells and growth factors into the body using via an ink.

This 'ink' contains human fat (adipose) cells from the patient, however it's also critical that we include growth factors as part of the ink to ensure these stem cells grow into the desired cartilage. My work specifically focuses on developing polymer implants that can be fabricated into suitable release mechanisms for these growth factors as part of the ink.

So far, we have developed hydrogel structures that are able to slowly deliver growth factors to stimulate growth in the living stem cells. Now, we're testing these structures to see if they can assist in muscle cell repair and regeneration.

Your background is engineering. How do you find being in a research lab?

I'm honoured to have the chance to collaborate with Professor Peter Choong's research group at St Vincent's Hospital Melbourne. Most of my work is with Dr Claudia di Bella (an orthopaedic surgeon), Dr Carmine Onofrillo and Dr Serena Duchi.

Working in the lab, surrounded by the conversations and discussions from a broad range of professionals is the favourite aspect of what I do.
By working next to medical students, engineers, microbiologists and biologists I can view my research from so many different perspectives. We really complement each other. If something isn't working, we can discuss it as a multidisciplinary team, and reshape the direction of the project and achieve a more effective outcome.

What do you hope is the ultimate result of your research?

My ultimate hope is that I can develop some fundamental knowledge that can be translated in a relatively short timeframe into making a difference to patient outcomes.

Having the opportunity to work in such a collaborative environment gives me the confidence that we're closer to translating this research into a practical application far sooner than if we were working in isolation.

Lilith was awarded a 2018 Research Endowment Fund (REF) Grant for her project, 'Fabrication of a chondrogenic hydrogel for in situ 3D bioprinting'. The REF grant is in recognition and support of high quality research activity across St Vincent's Hospital Melbourne campuses.

> “We are collaborating with prosthetists, hospitals and clinics, as well as reaching out to prosthetic users to determine and create an entire system including hardware and software to satisfy the end-user, the amputee.

Soft Robotics

INSPIRED BY NATURE: DEVELOPING BIO-INSPIRED SOFT ROBOTICS

They say fresh air is good for the brain, and for ACES CI Professor Gursel Alici, being outside in his garden has provided some ground-breaking advances for soft robotics.

While pottering around outside, Gursel stopped to smell the roses – well, not really – he paused to examine his fern trees.

“It was one of those ‘aha’ moments, as I stood there with my pruning shears and gardening gloves,” Gursel explained.

“The thin outer walls of the annulus of the sporangium of a fern tree, which is the on the outer rim, allow water to evaporate from the cells when the sporangium is exposed to air. Consequently, the annulus bends due to a negative pressure developed in each cell, which forces the radial walls to collapse.

“I began to wonder if we could use the same principle to achieve a bending motion in actuators for soft robotics when air is evacuated from each cell.”

Soft robotics is a rapidly developing field of research that seeks to combine biomimetic design principles, novel sensor and actuation concepts, and advanced manufacturing techniques to develop robotic systems that are made of soft and compliant materials.

Developing entirely soft robots remains a great challenge for researchers. Not only do you need to utilise soft materials such as silicone and other elastomers to form the structural shape of a robot, you also need to develop central controllers, power supply, sensors, and actuators for robots that mimic the behaviour of soft biological structures.

When these elements combine, you end up with a robot that is capable of safely interacting alongside humans in unstructured environments, when compared to conventional robots (Baymax from Disney’s Big Hero 6 versus Bumblebee from Transformers!).

The development of soft and compliant actuators and sensors is seen as one of the most critical challenges for the soft robotics field. An actuator is a component of a machine that converts energy into motion, and is responsible for moving and controlling a mechanism or system. In soft robotics, these actuators must be soft and compliant while also capable of generating large forces, dexterous movements, favourable relative precision, and exhibit fast and large reversible deformations.

Using Gursel’s thoughts around fern tree sporangium, the ACES soft robotics group at the University of Wollongong has developed novel bioinspired soft vacuum actuators, or SOVAs, that can be used in diverse soft robotic applications including walking robots, hopping robots, soft artificial muscles, soft adaptive grippers, and modular robots.

Click here to read more about soft vacuum actuators

The SOVAs are fully 3D printed, allowing them to be fabricated in one manufacturing step with off-the-shelf soft material and customised for specific applications. The SOVAs have fast response times, high output forces, high actuation speed, high payload-to-weight ratio, and a long lifetime.

Actuation is accomplished through vacuum, which eliminates the possibility of burst and bulging as found in conventional pneumatic actuators, thus increasing the lifespan and reliability of the SOVAs.

ACES CI Professor Geoffrey Spinks, who is part of the team leading this work, believes this newly developed soft actuation concept can play a significant role in the development of soft actuators and soft robots.

“As the actuators are 3D printed, they can be easily and rapidly manufactured using commercial and affordable fused deposition modelling (FDM) 3D printers,” Geoff said.

“Secondly, the actuators are safe and reliable as they have shown repeatability and long lifetime. Maintenance and replacement costs can be significantly decreased as the actuators can undergo thousands of actuation cycles before failure.

“The concept can also be used in a wide variety of robotic applications including grippers, locomotion robots, and artificial muscles, and we’re attracting interest from a range of companies interested in potential uses for soft grippers and soft prosthetic hands.”

This groundbreaking work has been recognised as one of the best technologies going round in soft robotics, with the ACES SOVA taking home two gold medals at the 2018 Institute of Electrical and Electronics (IEEE) International Conference on Robotics and Automation.

The competition aims to showcase newly developed soft robot technologies, including new actuators, sensors or other component technologies that advance the field of soft robotics. Entries are judged on significance, originality, functionality and quality of documentation. Next stop: the soft robotic hand.

These SOVAs are a critical part of the ACES team’s bigger plans to create a soft robotic prosthetic hand. It is estimated that 3 to 4 million people suffer from upper limb loss around the world, and most amputees wear cosmetic prostheses or even no prosthetic hand at all, especially those in developing countries.

ACES is one of the first research teams that is combining cutting-edge technologies including additive manufacturing, smart materials and soft robotics to produce a prosthetic hand as a monolithic structure, requiring minimum assembly, that is low cost, low weight, and readily customisable to the needs of users. As well as soft actuators, the group has been developing intuitive myoelectric control systems to control and power the prosthetic through the detection the electric signals generated naturally by our muscles.

Current commercial myoelectric hands are too expensive for most amputees to afford, and are constructed of a great number of components which makes them considerably heavier than biological hands.

A traditional myoelectric hand uses surface electromyogram (sEMG) sensors to detect a user’s intention of hand movements in order to control the hand, however current systems are limited to open, close and stop commands and fail to provide natural control.

The ACES team has been using machine learning and deep learning techniques to process the sEMG data to translate human intention into control signals to create a natural and intuitive control system.

The set up includes the development of a non-invasive haptic feedback system, which aims to close the loop of the prosthetic hand’s control system and bring back the perception of ‘hand touch’ to users, and a sEMG armband to detect user movement. These sensing elements allow for interaction between the robotic system and its immediate environment, including interactions with human beings.

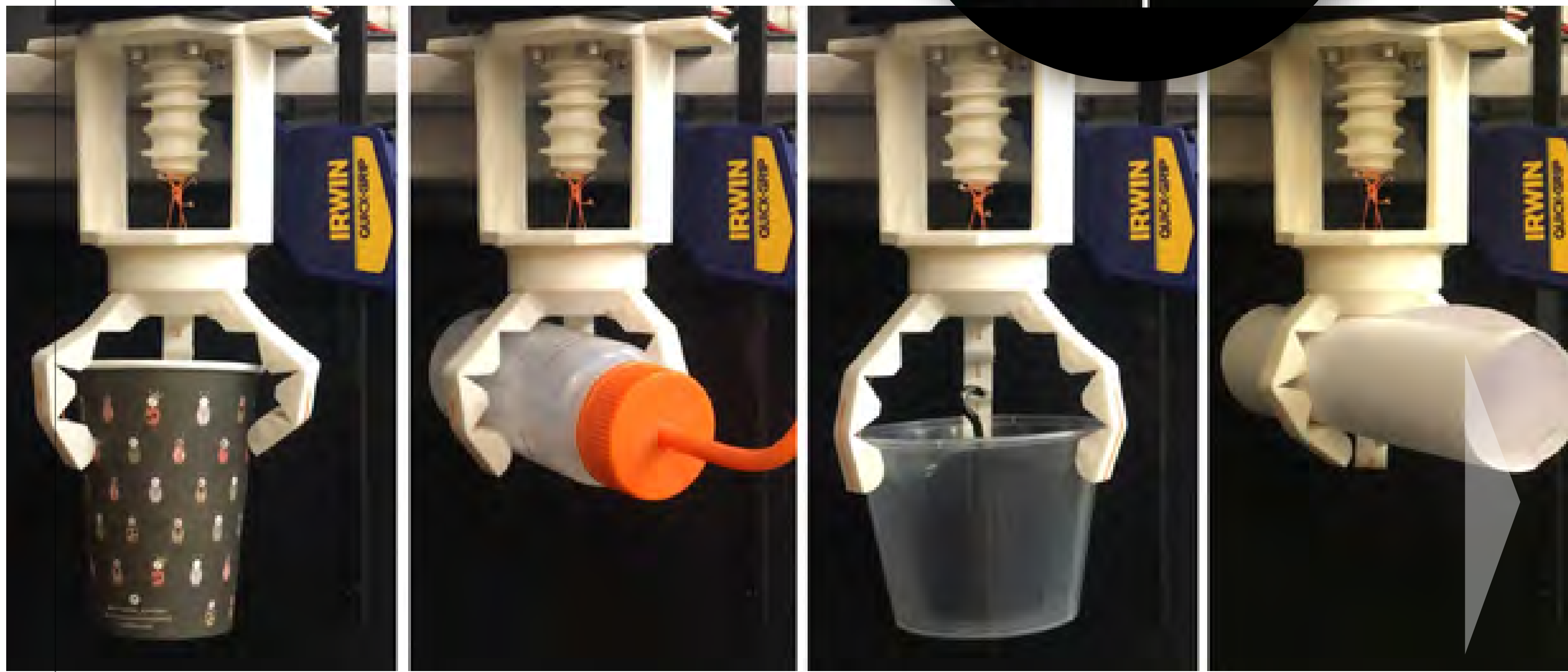
Gursel said the ACES group has achieved a significant step towards bringing technologies such as prosthetic hands one step closer to their natural counterparts.

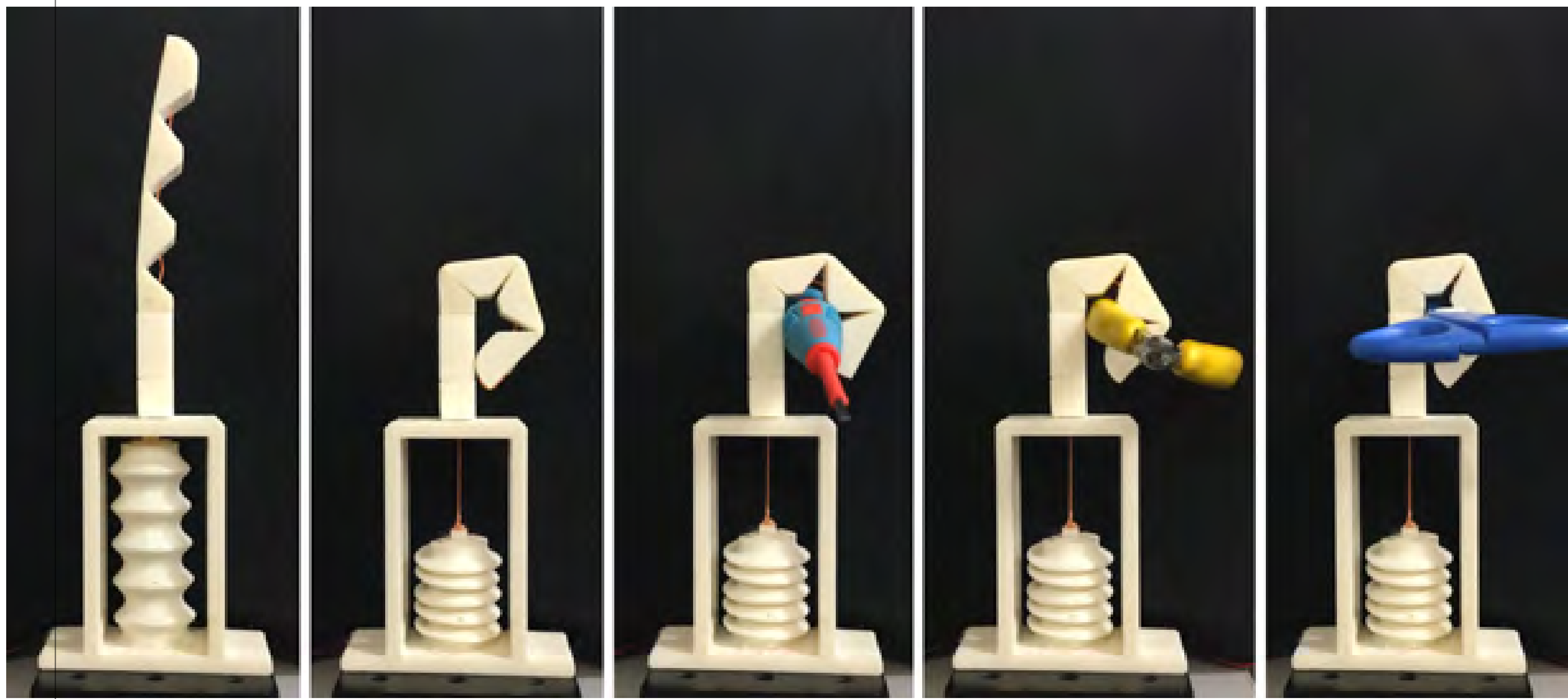
“Recent progress in enabling technologies including additive manufacturing and smart materials mean now is the right time to introduce a low cost, low weight, low power and low footprint myoelectric prosthetic hand with intuitive control and customisable features,” Gursel said.

“We are collaborating with prosthetists, hospitals and clinics, as well as reaching out to prosthetic users to determine and create an entire system including hardware and software to satisfy the end-user, the amputee.

“The sensors, control systems and soft robotic structures developed by our group could also be applied in a range of areas including orthotics, lower limb-prosthesis, wearable devices, rehabilitation and assistive devices for upper and lower limbs.”

‘Bioinspired 3D Printable Soft Vacuum Actuators for Locomotion Robots, Grippers and Artificial Muscles’ by Charbel Tawk, Marc in het Panhuis, Geoffrey M. Spinks and Gursel Alici was published in Soft Robotics, 7 December 2018 (Volume 5, Issue 6).





ACES RESEARCHER SPOTLIGHT

Dr Charbel Tawk – Soft Robotics Theme (University of Wollongong)

Dr Charbel Tawk developed 3D printable soft actuators and sensors that can be used in diverse robotic applications, including locomotion robots, soft adaptive grippers, soft artificial muscles, human-machine interfaces and soft prosthetic hands as part of his submitted PhD.

Read about Charbel's tips to finishing a successful PhD here

Robotics is a pretty broad field. Can you tell me more about the focus of your research?

Traditionally, robots are made of stiff and rigid components and are driven by electric motors and hydraulic or pneumatic actuators. They perform very well in automation and are capable of achieving large forces and high speeds with great precision. However, the fast movements and high forces generated by traditional robots pose some fairly critical safety issues when interacting with humans.

This has spurred the need for 'soft' robots for applications like soft adaptive grippers, soft artificial muscles, human-machine interfaces and soft prosthetic hands that can safely interact with more intricate environments better than rigid-bodied robots. Developing entirely soft robots that mimic the behaviour of soft biological structures remains a challenge – think of an octopus arm, an elephant trunk, squid tentacles, the human tongue – these structures we're trying to replicate in robotic form using compliant materials and liquids.

I'm currently developing 3D printable soft sensors for soft robots, human-machine interfaces and wearable soft sensors.

You've made some pretty interesting progress in the soft robotics field. What are some of the advances you've achieved?

As part of my research, we've developed novel 3D printable soft actuators that can be directly 3D printed using low-cost and open source 3D printers. One of the soft actuation concepts we developed is an award winner, taking out the gold medal in the Soft Component Technology competition at the 2018 International Conference on Robotics and Automation (ICRA). We also took out the gold medal in the Soft Grip Competition, where our soft robot completed a series of gripping and transport tasks with objects of various shapes, stiffnesses and weights such as a bar of soap, a USB stick and a banana, with the robot controlled wirelessly through a PlayStation game controller.

What made you pursue soft robotics?

When I was a kid I was really interested in mechanical systems and everything related to mechanical engineering. During my undergraduate studies, I became interested in mechatronic, robotics and programming.

I had the opportunity to work with Prof Barbar Akle at the Lebanese American University where I completed my Bachelor of Engineering in Mechanical Engineering, where I worked as an Undergraduate Research Assistant in Smart Materials in the Department of Industrial and Mechanical Engineering. In particular I optimised the manufacturing procedures of ionic polymer-metal composites, which are hair-like transducers that can be used as artificial inner hair cells in the cochlear. It was my time here that really developed my passion for robotics and the reason I decided to pursue a PhD in robotics.

What do you hope will ultimately come out of your research?

The ultimate goal is to ensure robots will be safer to operate alongside humans and to interact with them directly. More specifically, I'm aiming to develop tangible soft robotic devices that can be used in diverse applications such as soft prosthetic hands, soft human-machine interfaces, medical and assistive devices and soft robotic systems. My PhD is contributing to the fabrication of actuators and sensors for soft robotic devices that are more affordable, meaning they are easily accessible for the community and ideal for STEM education.

Charbel is the lead author on an article published in the Soft Robotics journal titled "Bioinspired 3D Printable Soft Vacuum Actuators for Locomotion Robots, Grippers and Artificial Muscles" (Published December 7 2018, Volume 5, Issue 6).

Access this article here

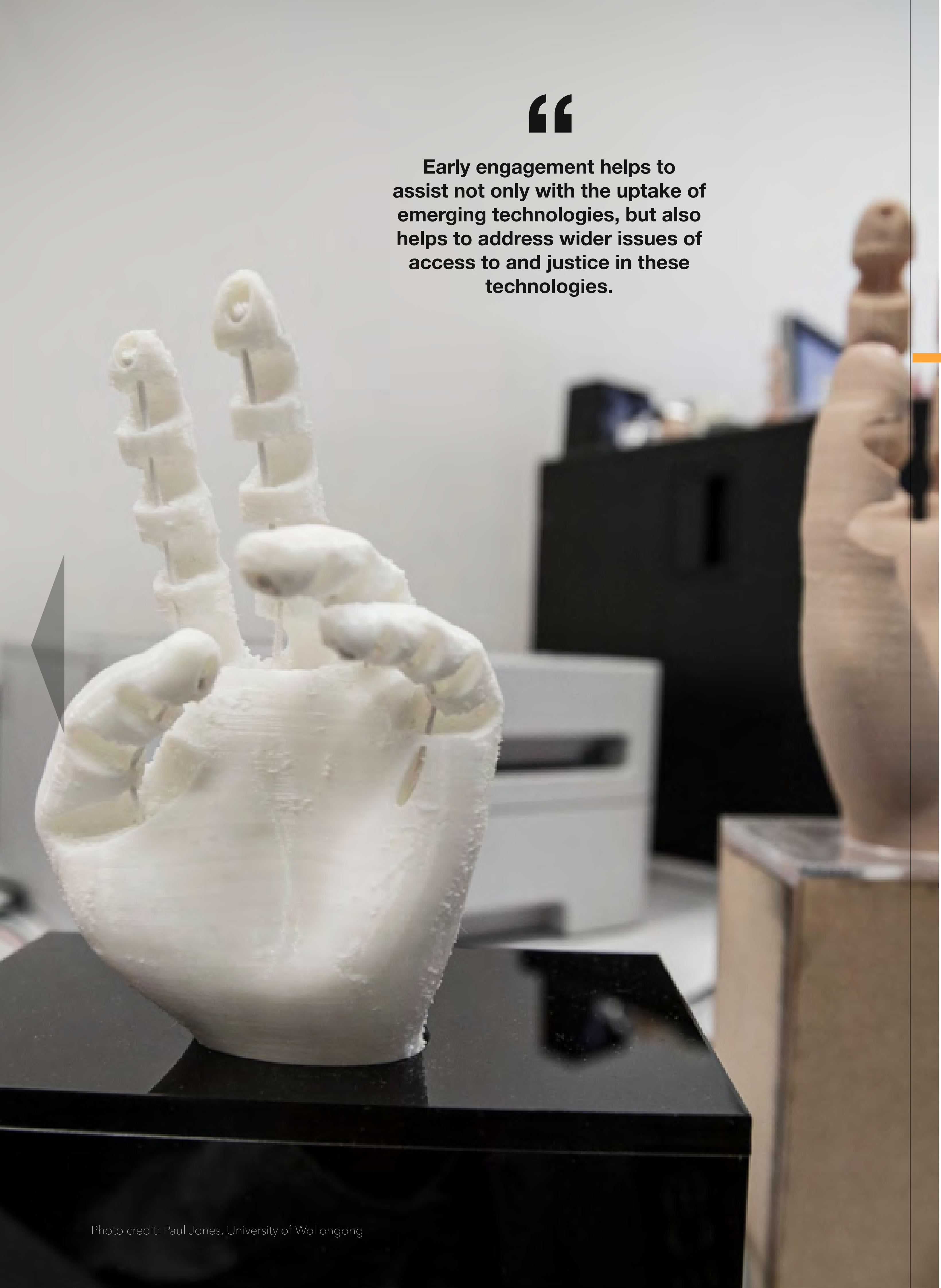


Photo credit: Paul Jones, University of Wollongong

Ethics, Policy & Public Engagement

PUTTING PEOPLE FIRST: THE ETHICS OF PROSTHETICS

Any savvy entrepreneur knows you don't start a business without doing some market research first. It's important to know all that you can about your customers, their preferences, desires and needs, and the marketplace you will be operating in. You don't want to sell ice to Eskimos.

The world of research is no different. For ACES Ethics, Policy and Public Engagement (EPPE) Research Fellow **Dr Eliza Goddard**, understanding the needs and wants of your end-users is paramount to the effective design and direction of fundamental research. Too often, however, this is not the case, with end-users included towards the end of the research process.

"As ACES progresses towards translation of research into practical applications, it's important we work with researchers, industry and the wider community to anticipate and address the ethical, policy and community concerns that arise from our emerging technologies," Eliza said.

"Early engagement helps to assist not only with the uptake of emerging technologies, but also helps to address wider issues of access to and justice in these technologies.

"There's no point in designing something that solves one societal issue but creates another in return. A breakthrough battery for clean energy might not be so sustainable if it uses rare materials that are mined in an environmentally and ethically harmful way. An innovative soft robotic hand is irrelevant if no one actually wants to use it and it fails to meet user needs. This is not just a market failure – it's an ethical failure also."

It is this latter point around people's experiences of and desires for prosthetics that brought together an interdisciplinary research team at ACES to investigate just what Australians with upper limb difference want in a prosthesis.

Check out our researchers' thoughts on prosthetics of the future here

The collaboration between ACES' EPPE and Soft Robotics team, with expertise in bioethics, engineering and biomedical device design, surveyed people with upper limb difference from across Australia to ultimately guide and justify ACES researchers using soft robotics and additive manufacturing for the next generation of customised prosthetic hands.

Despite a number of developments in device design in recent years, there are relatively low levels of uptake and satisfaction with current prosthetic design. Key concerns for users include the significant size and weight of current prosthetics, functionality and dexterity, aesthetics, and cost.

"Our research has shown that the desires and needs of people with upper limb difference in terms of prosthetics are diverse," said Soft Robotics Theme Leader and ACES CI Professor Gursel Alici.

"This is certainly a case where one size does not fit all, and we need to develop techniques that allow for tailor-made prosthetics. Our approach in combining soft robotic and additive manufacturing techniques enables the creation of cost effective, lightweight and customisable prosthetics to improve patient satisfaction and acceptance."

So, why soft robotics and additive manufacturing? Soft robotics is an emerging research area that utilises soft materials to establish conformable, lightweight, low cost and low footprint devices with programmable compliance to mimic parts of biological organisms. Soft robotic technology incorporates flexible bending points to adapt to the shape of the object being gripped or interacted with, rather than using multiple rigid components and joints as used in traditional robots.

Additive manufacturing is a process where materials are joined together to build an object one layer at a time, as opposed to traditional manufacturing where a material is carved away to achieve the desired shape.

This combination of a soft robotic approach with additive manufacturing can improve prosthetic devices in many of the ways potential users desire, including the creation of tailored, complex geometries and introducing finer dexterity control dexterity in a prosthetic, a high level of customisation for users in terms of looks and appropriate sizing, whilst minimising cost and weight.

Importantly, a soft robotic and additive manufacturing approach could lead to a bigger variation in hands available for purchase and provide the patient with the potential to afford multiple devices.

"Currently, an occupational therapist helps a user determine the most suitable prosthetic device for the user and their needs from a small number of models on the market," Gursel explained.

"Since additive manufacturing allows for relatively easy changes in design without additional production expenses when compared with traditional manufacturing, a potential future exists where a team could alter a variety of options important to the user, such as the hand's shape, weight, size and colour to help increase comfort and acceptance."

But are people's needs and desires really that different?

Eliza explains that the results of the ACES survey indicate that the needs and desires for prosthetic devices not only differ between users, including whether they felt the need to use a prosthetic, but user needs can also change as projects and life circumstances change.

"In one of the more interesting results, we received an incredibly varied response to the desires around, and reasons for, aesthetic appearance. Some participants preferred a natural look to their prosthesis, sometimes to minimise attention to their prosthesis, while others gravitated towards a more robotic/cyborg or skeletal/uncovered look, including for reasons to challenge assumptions about prosthetics and prosthetic users," Eliza said.

"Importantly, these responses demonstrate the role of prosthetics to user identity and points to the potential of innovative prosthetic design to positively address the needs, as well as perceptions of, prosthetic users and their capabilities.

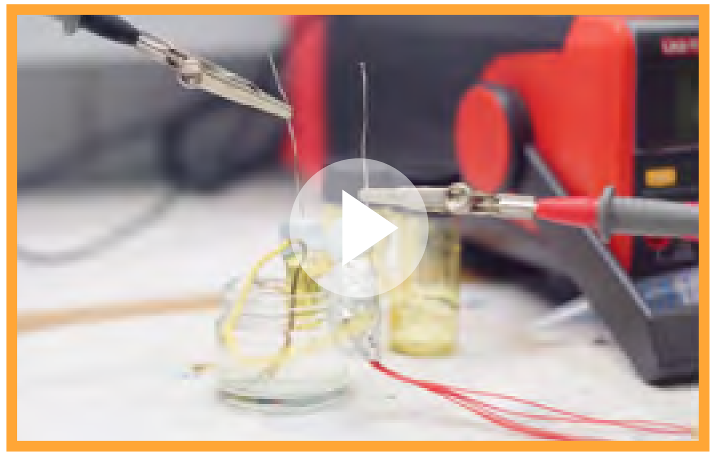
"As Gursel has noted, using a soft robotic approach for prosthetic hand design resulting from additive manufacturing presents an exciting pathway to achieve a broad range of user goals simultaneously, from look and feel to cost.

"By including users early in the process we can inform the use and design of that technology to meet user needs and aspirations, and in the end that's what we want our research and translation of that research to do – to not only meet the needs of society, but to improve on those possibilities."

'A survey on what Australians with upper limb difference want in a prosthesis: justification for using soft robotics and additive manufacturing for customized prosthetic hands' by Benjamin Stephen-Fripp, Mary Jean Walker, Eliza Goddard and Gursel Alici appeared in the Disability and Rehabilitation: Assistive Technology journal in March 2019.

Access this paper here

THE ETHICS OF RENEWABLE ENERGY



Considerations by **Professor Linda Hancock** and **Dr Natalie Ralph**

For researchers at ACES to meet our goal of turning fundamental knowledge of cutting-edge materials into practical applications to benefit the community, we can't live in a bubble. We must consider the wider, impacts this research can have. That's where we come in. As members of the Ethics, Policy and Public Engagement (EPPE) theme at ACES, it is our responsibility to ensure our researchers anticipate, understand, evaluate and respond to the ethical, policy and community concerns that arise from our emerging technologies.

A team within the ACES EPPE theme has been assessing the policy and supply chain aspects of renewables to assess their impact on equity, access, conflict and resilience, to then develop an approach to engagement of key stakeholders in new energy technologies. One of our projects assesses the ethical implications of using La Trobe Valley lignite brown coal in Victoria to produce hydrogen for export to Japan's 'green' hydrogen economy and fuel cell automotive industry. Sustainable energy is a critical focus across the planet, however there's no point in supporting green economies when the production of fuels is not so green.

In the case of La Trobe Valley, the jury is still out on the scientific merit of claims that the planned coal-fired gasification plant will sufficiently reduce fuel production emissions. This proposed project also relies on the contested merits of carbon capture and storage in Bass Strait with unproven carbon-neutral strategies. While coal jobs are a priority for the Victorian Government, the project will have to compete with more ethically-produced solar energy hydrogen in states like Queensland.

In 2017, the Intergovernmental Panel on Climate Change – the United Nation's body for assessing the science related to climate change – released a special report on the impacts on global warming of 1.5°C above pre-industrial levels and related greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change and sustainable development. In light of this report, the Australian government will need to consider the current domination in policy of fossil fuel path dependency, and respond to increasing global demands for ethically sourced renewable energy and energy exports that meet global ethical 'energy security' demands. At ACES, our researchers are conducting some amazing work in determining the future of green, sustainable energy – we must, however, make sure the materials and processes we use are also reducing our environmental footprint, not adding to the problem.

The EPPE team has also been examining energy security, transnational politics and renewable electricity in relation to exports in Australia and South East Asia.

In particular, we have dug deeply into the implications of an energy security framework for a pilot project looking to export solar-generated electricity from the Pilbara in Western Australia to Java, Indonesia. This proposal is significant for our researchers working to produce renewable energy technologies for export to Asia and beyond. A number of key questions arise for our team in looking at the potential risks and opportunities in terms of human security, foreign policy, materials energy politics, and new business and regulatory frameworks. When looking to assist with the development of technologies that will support the export of renewable energy, we must consider the impacts of price stability, affordability, access and equity for local communities, reliability and resilience risks and environmental impacts.

For the Australia/Indonesia project, our team has found that while potentially positive outcomes may arise for local (Indigenous) Australian communities who are partners in the project, more analysis is needed on whether Australian investment in exports should prioritise large-scale electricity grid infrastructure and/or distributed energy systems, when considering impacts on Indonesian communities. Just what are the impacts beyond our own borders? Ultimately, the expanded index developed by this research will inform development of new transnational renewable energy and electricity projects, and improve forward thinking of policy, regulation and risk management.

As ACES researchers transition from fundamental research to strategic applications, the ethics, policy and public engagement considerations of their work is more important than ever.

THE LAST WORD - FOR NOW

Professor Maria Forsyth, ACES Associate Director

At the ARC Centre of Excellence for Electromaterials Science, we have been privileged to be in a position to carry out world-leading research for nearly 15 years.

Since 2005, ACES has been at the cutting edge of electromaterials science, discovering new materials and developing new approaches to fabrication. In this time, we have made rapid advances in electrofluidics and diagnostics, soft robotics, new energy storage systems, and biomedical technologies.

Support received from the Federal Government has placed us in a world-leading position to provide a platform for development of new industries and export markets for Australia.

I am proud of the global powerhouse that ACES has become, contributing to internationally significant research areas that will ultimately become the basis of the next generation of business opportunities and jobs. Most importantly, I am proud of our team of extraordinary individuals who are committed to completing these translational pathways, and ready to engage to ensure it happens.

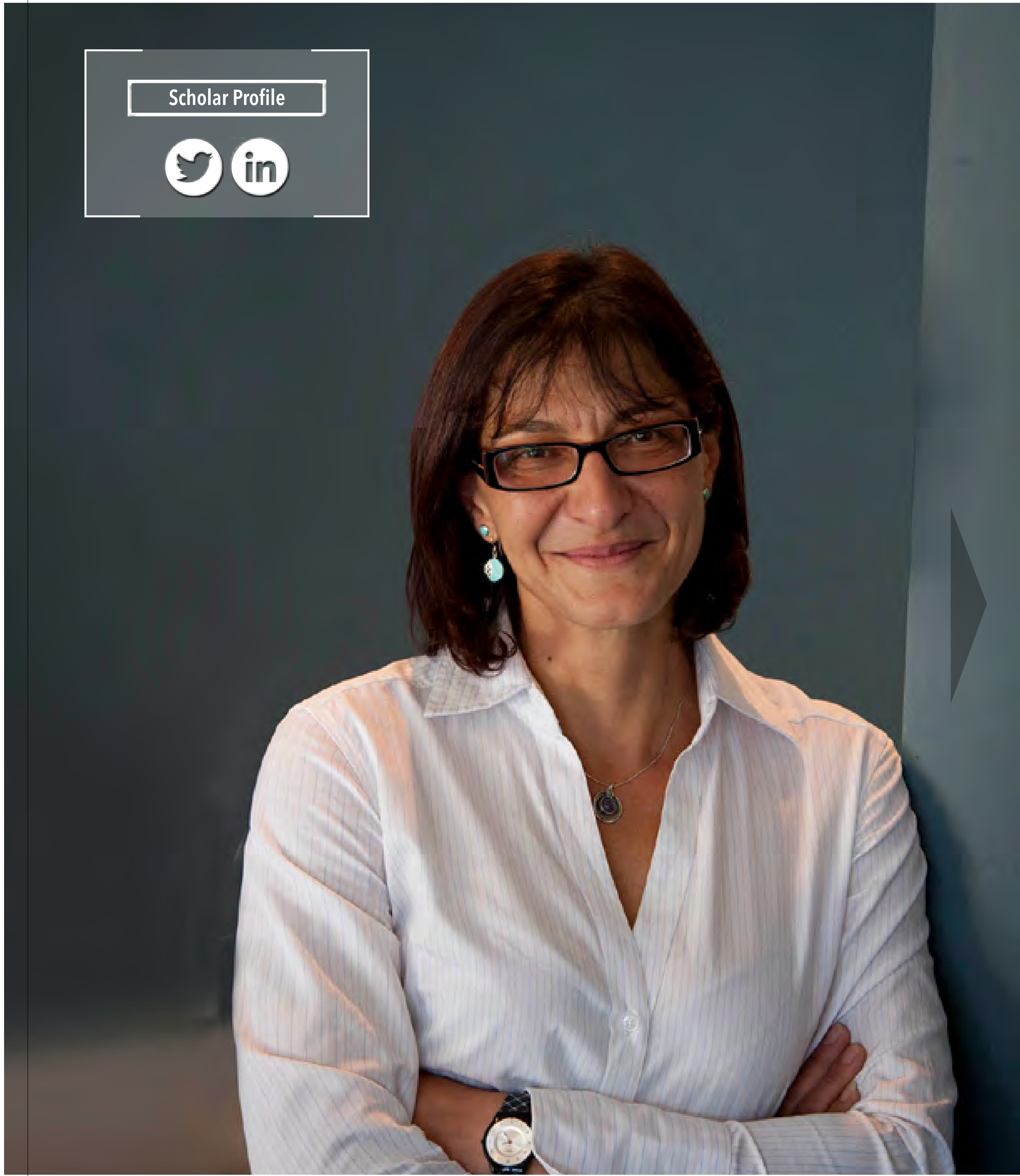
These translational outcomes provide career pathways for our researchers, trained and skilled to the highest technical level, as well as non-technical areas including science communication, ethical and regulatory issues, and commercialisation and entrepreneurship.
I am grateful for the wonderful group of scientists I collaborate with, both locally and internationally. It's through research collaboration and teamwork that we make real scientific, technological, clinical and industry breakthroughs.

More and more, we have found ourselves at the forefront of these breakthroughs, working side by side with experts to bring about better social outcomes. We are excited that ACES is producing ground-breaking research that compliments international research framework programs, including projects on graphene, battery technologies, solar-energy technologies, and biomedical technologies.

We have established a platform that allows leading international scientists and engineers to communicate their work to the next generation of researchers, to inspire us to continue to make the scientific and technological breakthroughs necessary to continue our transition towards a cleaner, healthier and more socially conscious society. We are committed to ensuring we continue to develop our future research and researcher capability in research areas that are considered critical across the globe.

While we recognise the importance of using our knowledge in electromaterials to create strategic, high impact applications, it is important to keep our strong fundamental research base so we can continue our responsibility to advance the field of electromaterials to deliver maximum impact to the communities we work for.

Now our challenge is to plot a path that ensures this holistic approach is enduring and continues to deliver.



CONTACT US:

W www.electromaterials.edu.au

T +61 2 4221 3127

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- Monash University
- University of Tasmania
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- Swinburne University of Technology
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