IMPACT STATEMENT

MAY 2021

ARC Centre of Excellence for
Electromaterials
Science

"Research is the key to unlocking intellectual capital, as well as bolstering its competitiveness, productivity and innovative capacity."
(Mary O'Kane, NSW Chief Scientist)

Since 2005, ACES has had a profound impact on the frontiers of electromaterials science and technology. ACES has generated products, technologies and services that benefit Australia and the world. The Centre has engaged broadly with national and international collaborations, community and education partners, along with industry allies.

The Centre's impact is penetrating into the scientific and general communities, as well as guiding Government decision-making to drive a global understanding of the value of electromaterials to human life. As such, ACES has forged a foundation for addressing some of humanity's most challenging global problems as outlined by the UN Sustainable Development Goals (UN-SDGs) in Good Health and Wellbeing (UN-SDG 3), Quality Education (UN-SDG 4), Affordable and Clean Energy (UN-SDG 7), Industry Innovation and Infrastructure (UN-SDG 9), Responsible Consumption and Production (UN-SDG 12), and Partnerships for the Goals (UN-SDG 17) - all areas of direct national benefit to Australia.

ACES' groundbreaking research is evidenced by 2041 publications, with 52.8% involving international collaborators, and gaining over 85,600 citations. Commercially, 53 patents have been filed, many of which have been used to build new commercial opportunities. ACES has successfully translated this research into innovative, commercially viable technologies and products for 'real-world' applications. Relevant to SDG Goal 17, Partnerships for the [SDG] Goals, industry partners have engaged

early with ACES research and have adopted new technology to match their individual company needs. Some examples include TRICEP (our industry partner platform), AquaHydrex (venture capital investment), and IMAGINE (IP Licensing).

UN-SDG (3): Good Health and Wellbeing

ACES has demonstrated the innovative use of electromaterials to control biological cell function in both 2D and 3D, which has global significance.

ACES has used electromaterials to make devices that integrate into the human body and restore function in failing tissue and systems. The following provides an overview of some of the most significant contributions:

Brain on a Bench (BoB): *Bioinks and fabrication tools make award-winning 3D printed brain-like tissues from human stem cells to enable new insights into brain function and tissue building.*

IMPACT CASE STUDY

Establishment of a Biofabrication Cluster

The Translational Research Initiative for Cellular Engineering and Printing - TRICEP - was established by the University of Wollongong (UOW) to grow Australia's capability in the development of innovative technologies using 3D bioprinting. It has developed a strong clinician (end-user) network while simultaneously facilitating the network of research groups and Australian biofabrication companies and to establish a strong and vibrant biofabrication industry on-shore.

Start-up companies such as Inventia, Axcelda and Anatomics are collaborating with TRICEP for R&D purposes and provide job opportunities for our highly qualified workforce. A former ACES PhD student, Dr Cameron Ferris, was recently appointed Chief Operating Officer for one of the businesses.

R&D partnerships have also been formed with Venus Shell Systems in the development of unique algae-based bioinks for application in wound healing. Relationships have been developed and MOUs have been signed with international biofabrication businesses from Portugal, US, India and Korea to enhance the global reach of ACES translational research.

The biofabrication industry globally is predicted to be worth $2 Billion by 2028, and the Australian biofabrication cluster has positioned itself to be a significant player.

"We are growing, extracting and fractionating now at a pilot commercial scale, and ACES is an invaluable partner in further modifying and fabricating wound healing dressings potentially from seaweed," *Dr Pia Winberg, Venus Shell Systems*

This research is impacting biomedical research and translation by enabling transition away from animal testing to human tissue modelling for pharmaceuticals discovery and laboratory-based medical device testing, as well as providing clinically relevant tissues for regenerative medicine. The BoB approach has evolved from ACES' award-winning work on 'electric neural tissue engineering'. This work was recognised by Research Australia through its inaugural 2019 Health and Medical Frontiers Research Award, which "recognises transformative research that extends existing knowledge and understandings within health and medical research that will enable Australia's health system to position itself as a global leader". The proprietary technology is enabling the development of advanced and customised tissues for ethical and more cost-effective biomedical research and prospective therapeutics.

Neurally driven prosthetics: *A monolithic soft hand prototype and cell-based electrode interface have impacted the area of prosthetic limb applications, providing significant improvement in quality of life for people with missing limbs.*

In the course of this pursuit 3D printed prosthetic hands with enhanced functionality driven by wearable electrodes, have been developed. In collaboration with patient advocacy groups and studies into desirable characteristics in a prosthetic hand, are ongoing patient trials in collaboration with Prince of Wales Hospital.

Axcelda Pen: *Development of a hand-held 3D fabrication tool to delivery stem cell therapies in degenerative disorders such as arthritis.*

This device will impact on the treatment options available to patients suffering from cartilage damage resulting from sports injury through to old age. Axcelda Pen provides a new way in which regenerative medicine will impact people's quality of life and in turn reduce the cost burden associated with current surgical interventions to repair cartilage damage.

3D Printed Ears: *The development of customised printers capable of producing hybrid structures that maintain shape while facilitating cartilage regeneration.*

In particular, ACES and surgeons have developed a customised multi-materials bioprinting solution to assist in the regeneration of cartilage for use in reconstructive ear surgery to treat microtia, a congenital deformity where the external ear is underdeveloped. In the course of this journey, a parallel project involving the development of a customised device to realise 3D printed prosthetic ears has emerged. Working closely with prosthetists in Australia and India, as well as AMTZ (Vizag in India), this project has been rapidly progressed. The complete package involves the use of mobile phones to scan the existing ear on a patient, providing data to enable printing of the prosthetic ear.

3D PICT: *Development of a customised 3D bioprinter for the delivery of islet cells to treat diabetes.*

The transplantation of donor islets is a potential cell therapy for Type 1 diabetes. ACES has developed a 3D Pancreatic Islet Cell Transplant System comprising a customised 3D PICT bioprinter and bioinks to deliver insulin-producing islets cells to revolutionise treatment for people with Type 1 diabetes. Prototype printers have been supplied to the Royal Adelaide Hospital and ASAN Medical in Korea.

Additionally, the ACES Synthetic Biosystems theme has been an integral component in the establishment of new facilities, including the BioFab3D@ACMD facility at St Vincent's Hospital Melbourne. This is a hospital-based biofabrication and biomedical engineering centre that embeds scientific research into

IMPACT CASE STUDY

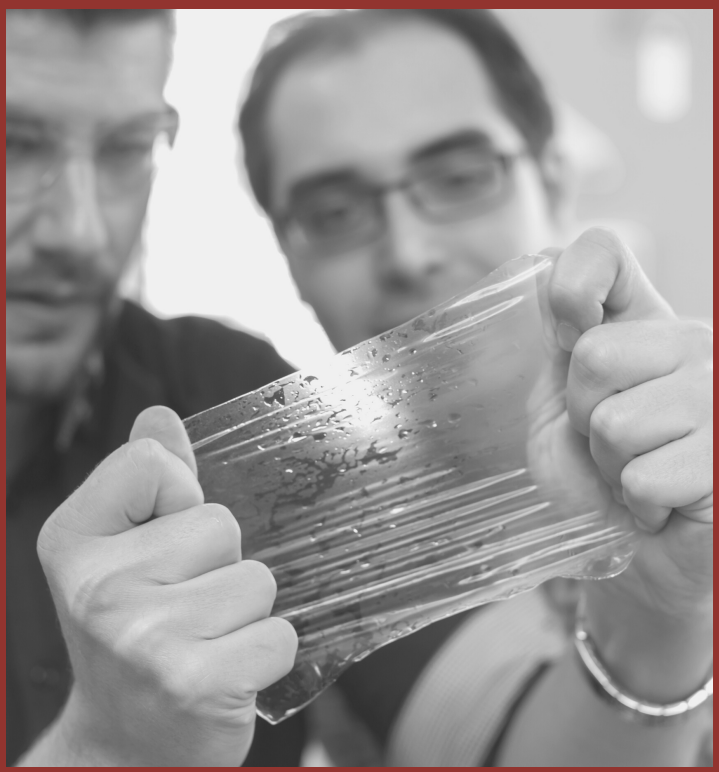
Eudaemon Technologies - Next Generation Condoms

ACES researchers developed a novel ultra-tough hydrogel condom to promote safe sex in third world countries such as Africa, where condoms are a taboo.

The hydrogel condom aims to mimic the feel of skin. The result is a soft, squishy condom that is non-allergenic, for those who are allergic to latex, that blocks viral molecules, bacteria and sperm.

The development of ultra-tough condoms received funding from the prestigious Bill and Melinda Gates Foundation. In 2018, the project was granted a further $1 Million from the NSW Government's Medical Devices Fund.

ACES-related next-generation condom technology is currently being commercially rolled out.



the clinical setting and clinical needs into the research environment, to increase and accelerate solutions for long-standing human health issues.

The Centre facilitates and expedites problem solving and instils greater context relevant to the research program through involvement of experts in the field, in tailoring solutions to their patients' real world problems and needs. This facility is a multi-institution facility (ACES partners UOW, RMIT, University of Melbourne, Swinburne University and St Vincent's Hospital, Melbourne), and has established vibrant collaborative research initiatives leading towards accelerated translation resulting in improved health impact. This facility also forms part of the Aikenhead Centre for Medical Discovery (ACMD), a AU$210 million multi-institutional facility, that will fuse medicine, engineering, science and industry to yield significant economic, patient and healthcare impact, unlike anywhere else in Australia.

UN-SDG 4: Quality Education

ACES understands technical research training is at the core of the impact we deliver and that today's graduates need to be able to contribute to interdisciplinary teams, communicate at all levels in society, adapt and re-skill to face new challenges and emerging opportunities. ACES provides students and ECRs with additional training in:

- Communication, to enable them to engage across disciplines and explain their research to the wider community;
- Entrepreneurship and Innovation via an intensive short course;
- Ethics and Public Engagement, so they are aware of ethical and policy issues that will arise from their research.

At ACES, the leadership team has taken a non-traditional approach to supervision and mentoring next-generation leaders. As a result of the multidisciplinary nature of the research carried out, we encourage researchers to work together in teams, and across traditional boundaries, and we provide access to collaborators' laboratories across the globe.

Innovative programs have been implemented to facilitate researchers to acquire skills in technology transfer and the commercial development of research. Beyond dedicated mentoring workshops or webinars, ACES exemplifies a culture of innovation, translation and building the confidence and resilience required to 'just have a go'. The educational scaffold provides by ACES allows our domestic and international student cohort to excel in their careers be it in industry, academia or their own entrepreneurial journey.

UN-SDG 7: Affordable and Clean Energy

ACES has developed new approaches to the use of renewables to drive water reduction to hydrogen, CO2 reduction of carbon based fuels and the reduction of nitrogen to ammonia. In particular, an Australian-

based platform of expertise and equipment in electrocatalysis relevant to chemical energy storage of ammonia or hydrogen has been established with strong international links. This concentration of expertise and equipment has led to the establishment of the Ammonia Energy Association Australian Chapter by the Monash node of ACES, which has

IMPACT CASE STUDY

AquaHydrex - Enabling Green Hydrogen

AquaHydrex is an innovative player in the hydrogen economy.

Based on ACES-funded research and IP at Monash University and UOW, a spin-out company, AquaHydrex P/L was formed, and began a scale-up and development program in 2011 with funding from a US-based private equity firm, True North Venture Partners Inc.

By December 2016, the company employed more than 12 highly skilled, mostly PhD level workers, many from within ACES, with first products being launched aimed at the industrial hydrogen market in Australia.

A $5 Million project to install a 'Power to Gas' demonstration device in South Australia using excess renewables in the grid was funded in part by the Australian Renewable Energy Agency. This demonstrator provides important technology leadership to the renewable energy industry and Australian community. It will provide detailed public insights into the techno-economics of utilising excess (low-cost) grid renewables for the production of hydrogen.

As well as commercialising ACES IP and producing net commercialisation income to Monash and UOW, AquaHydrex also created 20 new jobs and opportunities for ACES PhD graduates. The emergence of these new opportunities in engineering and manufacturing was particularly significant, as it coincided with the decline in the Illawarra's (New South Wales) steel manufacturing capabilities, representing crucial training for restructuring the region's economy.

"ACES is an example of a research organisation tackling commercially relevant problems at fundamental and applied levels. The talent of the team, coupled with the equipment and facilities to translate lab ideas to prototypes, is truly world-class. AquaHydrex appreciates the support of ACES and the Australian Government through its granting programs as it embarks on its commercialisation journey."
Steve Kloos, Partner at True North Venture Partners and Director of AquaHydrex

further resulted in frequent state and federal government briefings to shape and form future-orientated renewable policies. The Ammonia Energy Association also runs an annual conference to stimulate scientific discussions and developments on the same.

The ACES concentration of expertise and equipment as a Centre of Excellence has led to significant further funding from various sources. This includes industry-funded projects with Woodside Ltd and Applied Nanotechnologies P/L. Also, major research projects have been funded by the Australian Renewable Energy Agency (ARENA). These include the project "Ammonia Production from Renewables at Ambient Temperature and Pressure - Developing a processor reduction of nitrogen to ammonia", awarded to Monash University and the University of Wollongong, to the value of AU$2.4M (2019-2022) (Chief Investigators MacFarlane, Simonov, Swiegers and Wallace). This project aims to extend the ACES IP in the ammonia generation area to higher levels of Technology Readiness Level.

A second ARENA-funded project, "Low-cost, Robust, High-activity Water Splitting Electrodes" was funded to Monash University and the Australian National University to the value of AU$2.8M (Investigators Simonov, MacFarlane and Tricoli). This project aims to develop further the substantial catalyst IP within ACES in the field of water splitting to hydrogen, with a particular focus on inexpensive/ affordable energy materials and high through-put manufacturing.

The world-leading ACES expertise that has emerged in the ammonia field has led to new projects more broadly in sustainable nitrogen chemistry.

One project has been funded to the value of $935,000 as an Australian Research Council Discovery Project, "Sustainable Nitrogen Chemistry" (2020 - 2023). The ACES research led by CIs Pringle and MacFarlane has developed into a collaboration with local start-up company Energy Storage P/L in the thermal energy storage area. Thermal energy storage is increasingly seen as an emerging solution to low cost renewables storage. this venture includes licensing of technology and new ARC Linkage Project funding (2020-2023) to further develop the materials technology.

The Battery Technology Research and Innovation Hub (BatTRI-Hub): The BatTRI-Hub Director is ACES Deputy Director Prof Maria Forsyth. The hub draws on Deakin's critical mass of battery-related expertise, CSIRO's polymer research strengths and scale-up facilities, and ACES' electromaterials expertise.

BatTRI-Hub has facilitated engagement with industry projects including via CRC-P with Calix and Boron Molecular and the Future Battery Industries CRC, engaging with a number of companies and local industry through ITTC storEnergy. Without the fundamental science in ACES and BatTRI-Hub, these innovative collaborations would not have been possible.

Affordable and Clean Energy - Assuring Ethical Impact:
Contributing to both SDG 7 and Responsible Consumption and Production (UN-SDG 12), reflecting the ARC's support for multidisciplinary research linking STEM scientific research with ethics, policy and community engagement, has been the cross-node collaborations in energy-related research and publications in refereed international journals. This includes research on ethical renewables supply chains in university laboratory research; the relationships between disasters and resilient renewable energy systems; ethical battery supply chain research (Bolivia, India); circular economy in solar and battery research; ethical and international relations implications of international supply chains in renewable (solar) hydrogen exports to Asia; and policy implications of solar versus brown coal-generated hydrogen exports to Japan and South Korea.

Future policy impact includes PhD research focused on disaster-resilient renewable energy systems and policies in India and Australia-Germany comparisons of the policy and community impact of citizen-led low-carbon energy transitions.

CI involvement as a Board Director on the first Australian community wind farm (Hepburn Wind) has contributed to operationalising hybrid energy and negotiating current policy risks/barriers/opportunities for community-scale renewable energy.

UN-SDG 4: Industry Innovation and Infrastructure

Sustainable consumption and production is about doing more and better with less. It is also about the circular economy and ethical supply chains, decoupling economic growth from environment degradation, increasing resource efficiency, and promoting sustainable lifestyles.

ACES has focused on developing and characterising new electromaterials and creating structures and devices containing them. This has led to the development of new fabrication tools widely applicable outside the field of electromaterials.

These new fabrication strategies enable integration of newly discovered materials into structures and devices to enable translation. Selected examples that are traversing the

IMPACT CASE STUDY

3D MADe - Customise analytical devices

3D MADe (3D Printed Miniaturised Analytical Devices) is an initiative to bridge the gap between project requirements and commercially available analytical devices.

It is supported by ACES, the University of Tasmania, and the Australian Centre for Research on Separation Science.

3D MADe aims to empower researchers to personalise their analytical devices.

translational pipeline are illustrated below.

Graphene: A new form of graphene has been discovered by ACES researchers. The unique discovery of a multilayer edge functionalised structure has revolutionised graphene applications. This newly discovered structure is unique in that it has the combined features of high conductivity and high dispersability in water and organic solvents. This enables a variety of processing options to be utilised to create unique structures. This includes processing a range of composites with host polymers including polyurethane, latex rubber, and biomaterials such as chitosan and alginate.

Fabrication tools: New fabrication tools including a range of customised 3D printers have been developed by ACES researchers. Involving a multidisciplinary team of scientists and clinicians, ACES has developed the handheld Axcelda 'Biopen' (PCT/AU2016/050886) that enables biofabrication in a surgical environment. Further fabrication tools tailored to the surgical environment include the iFix system to treat wounds in the eye and 3D PICT, a customised printer to create constructs to facilitate islet cell transplantation to treat diabetes.

Development of these new fabrication tools has required the coordination of five interdependent streams of

IMPACT CASE STUDY

Imagine - Making all surfaces smart

Imagine Intelligent Materials was founded in 2014 based on ACES IP licence. The founders, from a background of materials science, signals processing and business, had a singular vision: to deliver infinitely scalable sensing systems using graphene, enabling every part of the built environment to communicate.

Imagine develops sensing solutions that deliver valuable data from large surface areas - in walls, floors, dams, roads and infrastructure. Dumb surfaces become 'smart'.

Imagine's graphene-enabled smart surfaces can be applied across many industries and application areas. They will provide invaluable data on: structural health, stress, pressure, leak and fire detection, asset monitoring, as well as human machine interfaces and control surfaces. Tangible innovative outcomes already include improving risk management, safety and productivity and creating new business opportunities for partners and customers. Imagine brings together the disciplines of materials science, signals processing and data science, to provide integrated sensing solutions for large surface areas.

Imagine is naturally very protective of its IPs and uses various methods to protect its assets, including patents, trade secrets, copyrights and know-how.

research available through the ACES network:

- Device development;
- Materials development, in combination with
- Biological development, through to
- Surgical implementation, and
- Ethics and regulation of a novel medical device.

Other fabrication techniques to create three dimensional (3D) structures include fibre spinning, knitting and braiding. These tools have been used to fabricate a range of wearable sensing and energy storage technologies.

Contactless characterisation tools: Additive fabrication of 3D structures and devices demands the development of contactless characterisation tools to monitor the physical and biological properties of materials during assembly. ACES researchers have developed new tools based on microwave and ultrasound interpretation that enable electrical and mechanical properties to be deduced.

Australian National Fabrication Facility (ANFF): Strong links to the ANFF Materials Node has paid significant dividends for industry take-up of ACES research. Industries, attracted by the ANFF materials processing and fabrication capabilities have subsequently engaged in longer term research (e.g. Enware, Romar Engineering and Venus Shell Systems). Emerging industries have used the ANFF capability to attract investment in new commercial entities based on ACES discoveries (e.g. AquaHydrex).

Fundamental research requirements emerging from ACES continually highlight the need for customised fabrication tools. UOW has established TRICEP - a facility for printing printers.

Diffusion of Innovation - Transforming local industry through ACES/ANFF partnership

ACES links to the ANFF Materials Node and has significant impact on the diffusion of electromaterials science research into local industry. Smaller scale R&D projects between local businesses and ANFF have resulted in longer term research collaborations supporting local industry in business transformation and innovation in product design.

Additionally, emerging industries have used the ANFF capability to attract investment in new commercial entities based on ACES discoveries (e.g. AquaHydrex).

"We wanted to be knowledge leaders, so we had to acquire that knowledge but we couldn't do it ourselves. Hence, we became involved with ACES. All of a sudden we were part of a community of experts well outside our field of knowledge, all trying to solve the same problem. What seemed to be impossible dreams were becoming realities, just from that knowledge in a room." Jason Hinds, Enware

"One of the highlights for us is staff exchange and industry placements. We invest in our projects with ACES and it's a great way of exchanging knowledge." Scott Edwards, SMR Automotive, part of Motherson Innovations