



ANU ENERGY CHANGE INSTITUTE ANNUAL REPORT

2018

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MESSAGE FROM THE DIRECTOR

2018 has been a milestone year for the Energy to work with the ECI over the next few years. The Energy Change Institute. The outstanding secondees will work on research programmes of mutual interest, including potentially the ECI Grand Challenge. achievement was winning the ANU Grand In the Federal Government sphere, 2018 saw yet another failure Challenge for our major transdisciplinary in the litany of attempts to create an energy policy to address climate change, following the scrapping of the National Energy research proposal, Zero-Carbon Energy Guarantee – the fourth such policy vetoed by the Coalition Party for the Asia-Pacific. The Grand Challenge room. This came at a time when our research shows that there is an almost unstoppable momentum building in Australia for the research program combines worldadoption of renewable energy at both utility and rooftop scale. leading ANU expertise in energy and in Our analysis of data from the Clean Energy Regulator published in The Conversation indicates that in 2018 and 2019, over 10 the Asia-Pacific - the region which will gigawatts of renewable generation capacity will be installed. create two thirds of the world's energy Whether this continues at that rate will depend to a large degree on Government policy certainty in the alignment of energy and demand growth in the next two decades. climate goals. But whatever happens, it is clear that industry has now demonstrated the capacity to not only eclipse the Renewable Energy Target in 2020, but also to meet our Paris We will receive \$10 million over the next five years to build 26% emissions reductions for the entire economy through transformation of the electricity sector alone - not by 2030, but by 2025.

on our \$0.5 million Interim Grand Challenge grant this year. We will expand our research team of early/mid-career Grand Challenge Fellows to work with our existing staff to build a transdisciplinary team for the next five years. Our research will focus on the technological, social and human science questions that will underpin a transformation in the way Australia trades with the world - and the Asia-Pacific in particular - based on renewable energy.

Together with our industry and other external partners we will investigate techno-economic pathways for the direct export of renewable electricity to Indonesia and beyond, as well as using renewable electricity to create value-added export products such as hydrogen and refined metals.

Hydrogen technologies are experiencing both a national and an international renaissance, with a focus on the opportunities to employ hydrogen as a zero-carbon energy vector for transport and energy storage.

ECI researchers this year won around \$4 million in ARENA funding for research that will feed into a future hydrogen economy, and we are investigating other avenues for expanding this enterprise in collaboration with researchers around the country. To reflect our strong research capability in this field, the ECI will establish a new research cluster on the hydrogen economy commencing in 2019.

2018 also saw the commencement of the ANU Battery Storage and Grid Integration program with the appointment of its research director and entrepreneurial fellow, Dr Lachlan Blackhall. This program, an \$8 million joint venture between the ACT Government and the ANU over 5 years, will create a joint team across the College of Science and the College of Engineering and Computer Science that will establish the University and the Australian Capital Territory as a key player in the field. We will also look to amplify this program through a broader collaborative enterprise with researchers from around the country to address the significant challenges to the grid as we transform our energy systems.

We have also embarked on a new public policy initiative thanks to a generous endowment from JWLand, which will fund joint secondments with the Department of the Environment and

This is indeed an exciting time for the ECI, which will continue in the coming years as we progress our research interests and increase our collaborative partnerships - especially in relation to our Grand Challenge Zero-Carbon Energy for the Asia-Pacific. We look forward to engaging with you on these opportunities over the coming period.

Professor Ken Baldwin ECI Director

HIGHLIGHTS

From ECI Open Day 30 October 2017 to Energy Update 29 November 2018.

ECI Open Day 30 October 2017

The ECI Open Day provides a platform for exchanging ideas for ANU based researchers and stakeholders working in the field of energy change. Highlights from 2017 included presentations from the UK's Chief Scientist, Professor John Loughead, Professor Andrew Blakers on Pumped hydro and 100% renewable energy futures, and a presentation by Chair of the Clean Energy Council's Women in Renewables, Natalie Collard. There were also presentations on the latest research by ECI members, an overview of two new ECI research clusters: Energy for Development and Sustainable Transport - and tours of the world-leading energy change research facilities at ANU.

ANU Energy Update and Solar Oration 29 November 2017

The annual ECI flagship event Energy Update brought together Australian researchers, policymakers, industry and members of the public to provide news on the latest world energy trends. Keynote speaker, Dr Alan Finkel spoke about implementing the National Electricity Market Review followed by lan Cronshaw of the International Energy Agency who presented the IEA's World Energy Outlook (WEO) 2017. Panels of expert speakers also presented their perspectives on two key WEO themes: China's Energy Outlook, and Making Sense of Australian Gas Policy.

The Solar Oration followed on from Energy Update and was delivered by Audrey Zibelman, CEO of the Australian Energy Market Operator (AEMO). Ms Zibelman discussed the major energy transition underway in Australia, from the rise of renewables, grid stability and emission reductions.

Ms Audrey Zibelman, CEO of AEMO and Dr Alan Finkel, Australia's Chief Scientist

Dr Matt Stocks is one of the inventors of the sliver cell technology. Image credit: Jamie Kidston, ANU

ANU-invented solar technology helps University reduce emissions 7 February 2018

ANU helped reduce its carbon footprint and its reliance on the electricity grid with the installation of ANU-invented solar panels on the rooftops of seven buildings around campus. 1,700 'sliver-cell' solar panels around ANU, including 600 on the National Computational Infrastructure (NCI) building, will provide about 265 kilowatts of electricity - enough to power around 60 households.

ECI signs MOU with US National Renewable Energy Laboratory 26 February 2018

The ANU strengthened its clean energy research collaboration with the National Renewable Energy Laboratory (NREL) in the United States under a new Memorandum of Understanding. The agreement between the ANU Energy Change Institute and NREL, which is part of the US Department of Energy, recognises the growth in shared energy research between the two organisations and will lead to new knowledge and greater sharing of results on clean energy.

Deputy Vice-Chancellor (Global Engagement) Prof Shirley Leitch and Dr Robert Margolis from NREL sign the MOU, in front of ACT Chief Minister Andrew Barr

JWLand enters partnership with ECI 3 April 2018

Property developer JWLand entered into a two-year partnership with the ECI to support renewable energy research. With a generous endowment by JWLand, the ECI has embarked on a new public policy initiative that will fund joint secondments with the Department of the Environment and Energy. The secondees will work on research programmes of mutual interest.

Dr Lachlan Blackhall

ANU announces new leader of battery storage program 6 April 2018

The ANU announced the appointment of Dr Lachlan Blackhall to lead an international research program to improve ways to integrate battery storage with the electricity grid. In this newly created position, Dr Blackhall will lead the \$8 million Battery Storage and Grid Integration Program jointly funded by the ACT Government and ANU.

Bruny Island Smart Battery Trial 12 April 2018

A trial of household solar and battery storage off the coast of Tasmania scooped three awards in 2018. Using a worldleading software platform developed at ANU Research School of Computer Science, the ARENA-funded project uses novel algorithms to automatically coordinate consumer-owned photovoltaic battery systems to provide network support and consumer value.

The Spit, Bruny Island

ECI establishes Women in Energy network 19 June 2018

In 2018 the ECI established an ANU-wide Women in Energy network to support ANU women researchers in the field of energy. Chaired by Professor Kylie Catchpole, from the College of Computer Science and Engineering, the network connects researchers across the University and offers opportunities for external networking and professional development. On 19 June the ECI hosted the inaugural ANU Women In Energy network meeting with a keynote speaker from the Clean Energy Council's Women in Renewables network, and panel members from across ANU, including Professor Margaret Jolly, Director of the ANU Gender Institute.

ECI Open Day 2018 19 June 2018

This year's Open Day was held in June. Highlights included a special guest presentation by Erik Ness, National Renewable Energy Laboratory, USA, presentations on new engagement with the Australian-German Energy Transition Hub and the Asian Renewable Energy Hub, and the latest research by ECI members including hydrogen technologies and transformations in the US energy market.

HIGHLIGHTS

MISSION

Lecture: Will the NEG transform Australia's energy landscape? 31 July 2018

In the lead-up to a COAG Energy Council meeting that would decide the fate of the now defunct National Energy Guarantee, a sold-out audience heard from a panel of stakeholders and experts including Mr Shane Rattenbury, ACT Minister for Climate Change and Sustainability; Professor Frank Jotzo (ANU); Dr Hugh Saddler (energy consultant) and Katharine Murphy (Guardian Australia).

ANU awarded 3.4m in renewable hydrogen research 7 September 2018

The ANU received \$3.4 million in funding from the Australian Renewable Energy Agency (ARENA) to progress Australia's hydrogen energy industry. ANU will also provide nearly \$1 million in matching funds. The successful ANU-led projects are:

- Low-cost perovskite/silicon semi-conductors integrated with earth abundant catalysts for efficient solar hydrogen generation: led by Professor Kylie Catchpole from the ANU College of Engineering and Computer Science.
- Improving efficiency, durability and cost-effectiveness of III-V semiconductors for direct water electrolysis: led by Professor Chennupati Jagadish from the College of Science.
- Bio-inspired hydrogen generation by novel bubble free electro catalytic systems: led by Professor Emeritus Ronald Pace from the College of Science.

Coming Up

ANU Energy Update 29 November 2018

Highlights of the upcoming Energy Update include: 2018 *World Energy Outlook* (WEO) presented by Ian Cronshaw from the International Energy Agency in Paris; a keynote address by Sarah McNamara, Chief Executive of the Australian Energy Council, and panel discussions on the WEO themes, *Electricity* and *Producer Economies*.

ACT Government/ANU annual Solar Oration: Can we make a 100% renewable electricity system? 29 November 2018

As the percentage of renewables in the system increases, we need to think about a range of issues beyond the cost generation, such as how to make it reliable. Ivor Frischknecht, who is presenting the Solar Oration, was inaugural Chief Executive Officer of the Australian Renewable Energy Agency (ARENA) for the six years August 2012 to August 2018. Ivor is widely acknowledged as an expert and innovator in the rapidly evolving energy industry.

Ivor Frischknecht, Solar Oration 2018 speaker

A key solution to the challenge of climate change is a world-wide shift to lowcarbon forms of energy. Energy change that drives this transformation to a clean economy will also offer wider benefits to society by increasing economic productivity, and by improving energy access and security. The ECI provides authoritative leadership in energy research, education and public policy through a broad portfolio ranging from the science and engineering of energy generation and energy efficiency, to energy economics, regulation, sociology, policy and security.

A defining feature of the ECI is that we are both technology and policy neutral. That is, we undertake research and education in key areas of energy technology and energy policy without favouring one particular area over another. This can and should create an open forum for good ideas leading to energy change.

GOVERNANCE

EDUCATION

Members of the ECI Executive team and Grand Challenge Steering Committee.

The ECI comprises more than 150 academic staff and their postgraduate research students, bringing the total complement close to 300 researchers.

The wider ECI membership meets every year at the Annual Business Meeting, which establishes the activity for the coming year. This year the ABM coincided with an ECI Grand Challenge kick-off workshop on 6 April 2018.

ECI Executive

Operationally, the ECI is governed by an Executive comprising representatives from ANU Colleges:

Professor Ken Baldwin – Director ANU College of Science

Professor Andrew Blakers (*Alternate Dr Matthew Stocks*) ANU College of Engineering & Computer Science

Professor Kylie Catchpole (Alternate Dr Fiona Beck) ANU College of Engineering & Computer Science

Professor Yun Liu (Alternate Professor Colin Jackson) ANU College of Science

Dr James Prest - Education Convenor (Alternate Professor Tom Faunce) ANU College of Law Professor Sylvie Thiebaux (Alternate Dr Lachlan Blackhall) ANU College of Engineering and Computer Science Dr Igor Skryabin – Research and Business Development Manager ANU College of Science

The Executive meets regularly throughout the year as required.

The strategic directions of the ECI are reviewed each year when the Executive meets with the ECI Advisory Board.

ECI Advisory Board

Professor Armin Aberle CEO, Solar Energy Research Institute of Singapore

Mr Brad Archer First Assistant Secretary, Department of the Environment and Energy

Mr Stephen Devlin General Manager, Evoenergy

Dr Bruce Godfrey Principal, Wyld Group Pty Ltd

Professor Mark Howden Director, ANU Climate Change Institute

Dr Sarah Pearson Chief Innovation Officer, Department of Foreign Affairs and Trade

Networking event for Master of Energy Change students. February 2018

Master of Energy Change

The Energy Change Institute coordinates the ANU Master of Energy Change degree program, a postgraduate degree combining a strong basis in the fundamentals of science and technology, with the opportunity to explore the economics, governance, and policy issues related to energy change.

This unique interdisciplinary offering, based on the expertise of the University's research staff across many fields, is equipping the next generation of energy decision makers from Australia and neighbouring countries with the knowledge and skills to help lead the energy revolution.

The degree is equally relevant to those with a technical or nontechnical background as it bridges the gap between scientific and engineering aspects of energy with insights from the humanities, law and economics. It provides students with the flexibility to focus on areas of energy innovation most relevant to their professional needs, interests and skills.

The degree includes two foundation courses and choices from 46 elective courses from almost all ANU Colleges. The foundation courses are:

- > Principles of Energy Generation and Transformation
- > Energy Resources and Renewable Technologies

These courses are aimed at providing students who do not have a technical background with an understanding of the principles underpinning energy technologies. Subjects are grouped in the key disciplines of:

- > Energy regulation and governance
- > Energy economics
- > Climate change
- > Environmental sustainability
- > Specific energy technologies (solar, wind, nuclear etc.)
- > Energy sociology and risk.

In addition to the formal coursework, Master of Energy Change students can participate in the wider activities of the ECI, which include a multitude of seminars, conferences and workshops at ANU engaging with government and industry. In 2018, we helped arrange student internships with Federal Government departments and local offices of the renewable energy industry in Canberra.

The Master of Energy Change program prepares graduates for careers in energy-related national and international roles in business, government, and NGOs. Our graduates find employment in energy companies, technical and business consultancy, all levels of government departments and agencies covering energy and climate, as well as in sustainability management, energy and greenhouse audit, energy market analysis and climate and energy project development and financing.

Marketing of the degree continues via video, internet and traditional channels. We are confident that the degree will continue to grow, offering exciting learning opportunities to our students based on our leading edge research and very strong links with the local and national energy sector. We continue to receive applications from across the Asia Pacific, as well as from the Middle East, Africa and the Americas.

EDUCATION

New in 2018

Student exchange with prestigious French university

2018 saw the launch of an exciting new student exchange opportunity with the École Polytechnique, one of the most prestigious and selective French grandes écoles, specialising in science, engineering and innovation.

Exclusive scholarship for Master of Energy Change students

The Prosser Scholarship was launched to support a domestic first year Master of Energy Change student. Funding has been provided by Jennifer and Ian Prosser, Canberra residents who value the importance of an interdisciplinary approach to energy change, and who wish to support regional and rural students.

Master of Energy Change Convenor

Dr James Prest

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Professional Short Courses

The Energy Change Institute offers state-of-the-art professional short courses and briefings for government departments and commercial participants. ECI short courses are designed to provide updates on recent advances in the science and technology, and in the social, policy, economic and governance aspects of energy change for policy makers and professionals.

A typical course comprises a numbers of sessions presented by leading ANU academics, with each topic presented by an expert in the field. They can be tailored to meet the needs of a specific audience, and can be scheduled over consecutive days or spread over weeks. Alternatively a short briefing session on a specific topic can be arranged.

Short course: Energy literacy for professionals 13 November 2018

In response to many enquiries, the ECI hosted a one-day short course entitled: 'Energy literacy for professionals'. The course was tailored for professionals with a technology, policy, business or economics background and focused on energy generation, transformation and storage.

"The materials and lectures were aimed at those who have some general understanding but did not have direct experience or training in technologies for energy generation, transformation and storage," said Dr Igor Skryabin, course convenor.

The course covered:

- > Energy technology and efficiency fundamentals
- > Interplay between technologies, their grid integration and policy development
- > Energy Futures an outlook on future energy systems and their transformation both in Australia and internationally.

Course participants included professionals from the Department of the Environment and Energy; Department of Defence; the Clean Energy Regulator, Evoenergy; the Office of National Assessments and the Australian Renewable Energy Agency (ARENA).

Professional Short Course Convenor

Dr Igor Skryabin Research and Business Development Manager Energy Change Institute

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- W energy.anu.edu.au/education/professional-short-courses

Taking a holisitic approach to the energy challenge

Rahul Ravindranathan moved to Australia from India to study the Master of Energy Change degree at ANU in 2018. With a background in electrical engineering and business

"In order to achieve a holistic approach to energy, I needed to gain knowledge in these other areas as well," said Rahul. "Australia is one of very few countries to offer this multi-disciplinary approach and the Master of Energy Change degree was the best fit for my requirements."

Rahul has embraced University life since arriving in Canberra in February this year. He is a member of the Postgraduate and Research Students' Association and is interning with the ANU to develop its Energy Master Plan – a research-led partnership of ANU expertise that will create a world-class, energy efficient, low carbon campus complete with its own electricity micro-grid. "Working on the ANU Energy Master Plan will help me implement some of my learnings at a practical level and understand better the potential hurdles and barriers involved," said Rahul.

Rahul has some advice to offer those considering studying in the field of energy. "For those looking at the bigger picture with respect to overcoming the energy crisis that the world is facing, the Master of Energy Change degree based on your professional goals and helps in filling in the knowledge gaps. Another benefit I hadn't considered before starting my degree is how useful it is to interact with students from other countries and learn more about the energy cituation in their bone countries " coid Pobul energy situation in their home countries," said Rahul.

with government bodies or multi-national development agencies in developing suitable policies and projects to implement the switch from a fossil fuel based economy to a green and sustainable economy.

L to R: Professor Andrew Blakers and Associate Professor Klaus Weber stand behind ANU-invented 'sliver' solar cells. This technology was invented by Prof Blakers and A/Prof Weber along with Dr Matthew Stocks and is in use across the campus.

This year's Annual Report provides an overview of research conducted within each of the ECI's 19 research clusters.

The research programme covers a broad spectrum from energy science and engineering, to implementation expertise in the economic, legal, security, sociological and policy issues surrounding Energy Change. This broad portfolio of research activity brings together researchers from all Colleges of the University and is unique in the country.

The number of ECI researchers exceeds 150, which together with PhD students yields close to 300 researchers in total.

- > Artificial Photosynthesis
- > Carbon Capture & Storage
- > Energy & Security
- > Energy Economics & Policy
- > Energy Efficiency
- > Energy for Development
- > Energy Regulation & Governance
- > Energy Sociology & Risk
- > Energy Storage & Recovery
- > Energy-Water Nexus
- > Enhanced Oil & Gas Extraction
- > Fusion Power
- > Nuclear Science
- > Renewable Fuels
- > Smart Grid
- > Solar Photovoltaics
- > Solar Thermal
- > Sustainable Transport
- > Wind Energy

To find out more, go to energy.anu.edu.au/research

Artificial Photosynthesis

The Artificial Photosynthesis research effort at ANU focuses on the mechanism of water-splitting; the fundamental processes and efficiencies of biological photo-energy conversion; and the design and properties of biomimetic molecular assemblies.

In September 2018 Associate Professor Ron Pace led a team from ANU and the University of Wollongong in winning an ARENA grant of \$600k to develop and deploy a "Bio-Inspired Hydrogen Generation by novel Bubble Free Electro-Catalytic Systems". Water splitting in nature occurs at the manganesecontaining catalytic centre, known as the Oxygen Evolving Complex (OEC). Recent advances at ANU have revealed key understandings of this natural electrolysis process, which is the most efficient known.

Professor Elmars Krausz and his collaborators have found an entirely new type of oxygenic photosynthesis, displayed by an extremely robust cyanobacterium which utilises a farred absorbing chlorophyll to perform its photochemistry. This discovery, published in the top academic journal Science, received world-wide recognition and exposure. This discovery has far-reaching consequences, as the system uses significantly lower voltages to perform oxygenic photosynthesis. The Krausz group has also perfected a remarkable new technique to identify the redox state and magnetic properties of each manganese in the cluster of four such ions in the OEC, which is responsible for water splitting in nature.

Dr Nick Cox, ARC future fellow and new faculty member at the Research School of Chemistry, is developing Australia's first high-field electron paramagnetic resonance facility as well as a new highly flexible and uniquely capable optical spectroscopy lab, set to target artificial photosynthesis, structural biology and materials science applications.

Professor Mark Humphrey is continuing a collaboration with colleagues at Tongji University (China) that is developing new approaches to metal carbide nanoparticles for hydrogen generation. His work in chemistry has been recognised by the award the 2017 Royal Australian Chemical Institute Leighton Memorial Medal.

Professor Tom Faunce has completed an ARC Discovery Grant project tasked to explore governance challenges involved in globalising artificial photosynthesis. Publications include articles in "Photochemistry, Advanced Sustainable Systems" and "MRS Energy and Sustainability". Tom has also written a science fiction novel exploring the wide-ranging changes possible in a world of global artificial photosynthesis "Split By Sun" World Scientific 2018.

Cluster Members: Convenor: Professor Elmars Krausz Dr Nick Cox Professor Tom Faunce Professor Mark Humphrey Dr Hemant Kumar Mulmudi Professor David Ollis Associate Professor Ron Pace Dr Robin Purchase Professor Robert Stranger

Associate Professor Ron Pace led a team from ANU and the University of Wollongong in winning an ARENA grant of \$600k to develop and deploy a "Bio-Inspired Hydrogen **Generation by novel Bubble Free Electro-Catalytic Systems**".

Carbon Capture and Storage

Carbon Capture and Storage (CCS) involves the capture of emitted carbon dioxide (CO₂), either directly from the atmosphere or before it enters the atmosphere, followed by storage, usually in porous rocks deep underground. With global emissions continuing to rise, it is becoming clear that negative emissions technologies such as CCS will be essential if humanity is to prevent extreme impacts from climate change. CCS is relevant for electricity as it has the potential to capture the CO_o produced by burning fossil fuels or biomass and store it before it enters the atmosphere. In the case of biomass, CCS can be a negative emissions technology, although cost remains a challenge. Alonaside electricity, CCS is the only medium-term option for reducing emissions from major industrial processes such as the production of steel and cement, where it is very difficult to displace fossil-fuel energy sources.

Gas Capture and Storage using Supramolecular Cages

The Ward group in the Research School of Chemistry has been working toward gas capture/storage using main-group element discrete supramolecular cages. These species have the advantage of being soluble in common solvents and synthesised with relative ease. Recent developments have focussed on the use of main-group element nodes bearing additional coordinating groups to both increase the binding affinity of guest molecules, but also to increase the level of partitioning within the supramolecular cavity, which in turn increases the available surface area for guest species to bind to. These species have been successfully synthesised and characterised, with testing of their binding properties currently in progress.

Efficiencies in calcination/carbonation looping processes

3D X-ray micro-tomography image that captures the distribution Innovations in CO₂ separation and regeneration (the capture of carbon dioxide (blue) and water (green) within the pores of a side) are critical because these steps in the CCS chain currently porous sandstone under high temperature and pressure conditions account for around 80 per cent of the cost of CCS, and also (mohammad.saadatfar@anu.edu.au). consume the most energy. Associate Professor Rowena Ball from the Mathematical Sciences Institute and the Research exist. Secure storage of CO₂ is possible given enough capillary School of Chemistry developed a new technology, Endex calcium or residual trapping. Such trapping depends on the interaction looping, for capturing carbon dioxide from fuels and flue gases, between existing water and the injected CO_a inside subusing mathematical modelling and computational simulation. millimeter tunnels in the rocks. Using the unique 3D microscopy Endex technology reduces the cost of CCS and has been capabilities of the ANU's National Centre for X-ray Microcommercialized by an Australian and European-British company, Computed Tomography, Drs Anna Herring and Mohammad Calix Ltd. Thermodynamic analysis carried out by Ball shows an Saadatfar have conducted fully-imaged core-flow studies of efficiency gain - or op-ex reduction - by a factor of two or more water and high-pressure high-temperature CO₂ in a supercritical for Endex CO_a capture over conventional methods. In addition to state (scCO₂), exploring the trapping potential of heterogeneous reducing CO, emissions, the technology has further impact: fitted rock formations. These studies are focusing on pilot storage sites to power plants co-fired with biomass it can effect net removal of in the Otway basin in Victoria and Queensland's Surat basin with CO_a from the atmosphere. support of Australian National Low Emissions Coal Research & Development (ANLEC R&D). Our research has shown that water-wetting conditions are highly likely to prevail at subsurface conditions in these aguifers, greatly increasing confidence in CO₂ storage at these sites.

Subsurface Carbon Storage

In geo-sequestration the big questions lie in the long-term security of proposed underground storage - while secure storage is certain to exist in depleted oil reservoirs, lower cost alternatives

Cluster Members:

Convenor: Professor Adrian Sheppard Associate Professor Rowena Ball Professor Justin Borevitz Associate Professor Stewart Fallon Dr Anna Herring Associate Professor Penny King Professor Mark Knackstedt Dr Mohammad Saadatfar Professor Tim Senden Dr Xiaolin (Shannon) Wang Dr Jas Ward Dr Nicholas White Dr Zongyou Yin

Energy and Security

ECI researchers examine energy and security in terms of supply, demand, critical infrastructure and environment, as well as the flow on effects for political, economic, and commercial realms.

The relationship between energy and security has its origins in global supply shocks and supply chain risks. It now incorporates a broad set of issues, including the security and resilience of electricity supply systems, the implications of climate change for environmental and human security, the nexus between decarbonisation of the electricity grid and security of energy supplies, and the relationship between geopolitics, energy and national security. Australia is at the centre of many of these policy issues given its position as a major energy supplier to the Asia-Pacific region, particularly as this region is expected to constitute half of all new global energy demand by 2040.

With an interdisciplinary membership, energy and security cluster members actively collaborate with colleagues and partners from industry, government, policy and academia, within Australia, the region, and globally. Recent projects have included potential regional cooperation around energy and security (including Paris Agreement and the Iran Deal), energy conflict and geostrategic tensions, and the destabilising consequences of climate change. Contributions and outputs spanned academic presses, public events, executive education, and media engagement.

Recent Research Projects have focused on:

- > Geopolitics, energy and security in the Asia Pacific
- > Climate change mitigation, and human and environmental security
- > Decarbonisation and energy security
- > The security and resilience of energy supply systems
- > Global energy governance and conflict

Australia is at the centre of many of these policy issues given its position as a major energy supplier to the Asia-Pacific region, particularly as this region is expected to constitute half of all new global energy demand by 2040.

ECI energy and security members contributed a submission to the Australian Senate Inquiry on the Implications of Climate Change for Australia's National Security, in August 2017 entitled "Mitigating Climate Change for National Security: the Role of Climate Mitigation Policies in Reducing National Security Risks". The full submission is available here: https://docslide. us/documents/submission-to-the-senate-inquiry-on-theimplications-of-cci-climate-and-security.html

Cluster Members:

Convenor: Dr Jennifer Hunt Adjunct Professor Chris Barrie Professor John Blaxland Professor Roger Bradbury Dr Elizabeth Buchanan Dr Christian Downie Professor Quentin Grafton Dr William Grant Associate Professor Llewelyn Hughes Professor Rory Medcalf Associate Professor Brendan Taylor

In February 2018, the research cluster hosted an Energy Security panel as part of the Symposium on Cooperation between Australia and Japan as Global Partners. Topics included global energy trends and their impacts on technical, diplomatic and political cooperation in the region.

In November 2018 a number of Energy Change Institute members contributed to a special energy edition of the College of Asia and the Pacific's publication Paradigm Shift. Edited by Dr Christian Downie, 'Securing our Energy' is a collection of expert essays on the challenges and opportunities of energy security, energy access and climate change. Download the publication at: http://asiapacific.anu.edu.au/energysecurity

Energy Economics and Policy

Expertise in energy economics and policy at ANU is concentrated in the Crawford School of Public Policy and the Research School of Economics, drawing on disciplinary strengths in economics and political science.

The Centre for Climate Economics and Policy (CCEP) anchors a network of Australian and international researchers providing insights on the economics of climate change, its implications for public policy, and the design of policies for zero-carbon energy systems. The Climate and Energy Program of the Centre for Applied Macroeconomic Analysis (CAMA) is an international network of scholars working in climate and energy, integrated with the Climate and Energy Economics Project at the Brookings Institution in Washington DC.

A major recent development has been the launch of the Australian-German Energy Transition Hub, a collaboration between the Australian National University, the University of Melbourne, the Potsdam Institute for Climate Impact Research (PIK), Münster University's Centre of Applied Economic Research, and the Mercator Research Institute of Global Commons and Climate Change (MCC). The Hub seeks to identify and create economic and technological opportunities from the global transition to clean energy.

In 2018 ANU ranked among the five most productive research institutions globally on market mechanisms for carbon emission reductions.

A key focus of economics research within the cluster is how to design energy-sector policies and approaches to deliver reliable, affordable, and clean energy. Reflecting ANU's long-running research in this field, an analysis carried out in 2018 ranked ANU among the five most productive research institutions globally on market mechanisms for carbon emission reductions. The analysis was based on bibliometric records between 1992–2016, and published in the journal Natural Hazards.

Professor Frank Jotzo was one of three ANU researchers appointed as lead authors for the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report, which will be published in 2022. He was also appointed as joint editor-inchief of the journal Climate Policy. Professor Jotzo also led the Australian component of the Coal Transitions research project, which aims to develop credible and feasible trajectories and policy guidance for deep transitions in the coal sector in major coal-using countries. Together with Salim Mazouz and Dr Hugh Saddler, Professor Jotzo was also heavily involved in analysis and engagement on the government's proposed National Energy Guarantee.

The Australia Indonesia Committee engaged Professor Kaliappa Kalirajan and Dr Arif Syed to develop cost estimates for the Indonesian Technology Energy Assessment (IETA). Professor Kaliappa Kalirajan also co-edited a book titled Financing for Low-carbon Energy Transition: Unlocking the Potential of Private Capital, published by ERIA and Springer in 2018. Dr Christian Downie commenced an Australian Research Council DECRA that aims to improve how energy is governed at the global level.

Cluster Members:

Convenor: Dr Paul Burke Dr Imran Habib Ahmad Dr Emma Aisbett Professor Robert Breunig Professor Bruce Chapman Honorary Associate Professor Simon Corbell Professor Robert Costanza Dr Matthew Dornan Dr Christian Downie Professor Quentin Grafton Associate Professor Carolyn Hendriks Honorary Professor John Hewson Associate Professor Llewelyn Hughes Professor Frank Jotzo Professor Kaliappa Kalirajan Dr Andrew Kennedy Dr Ida Kubiszewski Professor Warwick McKibbin Adjunct Professor Robert McMullan Dr John (Jack) Pezzey Dr Maria Racionero Professor Martin Richardson Honorary Associate Professor Hugh Saddler Professor Ligang Song Professor David Stern

Photo: Dr Paul Burke (far left) and Professor Budy Resosudarmo (third from left) with colleagues from the Indonesian Institute of Sciences (LIPI) in July 2018.

Christian's work on strategies to overcome political resistance to a clean energy transition in the United States was published in Energy Policy. Professor David Stern published a paper in Climatic Change on the International Energy Agency (IEA)'s projections for the energy intensity of the global economy. His paper concluded that reductions in energy intensity are likely to occur more slowly than the IEA has projected. Dr Paul Burke published a paper in Energy Policy finding that countries with carbon pricing systems have also been more successful in adopting solar and wind energy.

Energy Efficiency

Energy efficiency and demand management strategies are central to reducing energy demand growth. Investing in energy efficiency and demand management is also the lowest cost strategy to reduce greenhouse gas emissions. A range of ANU academics across three colleges undertake research in the fields of energy efficiency and demand management.

According to the International Energy Agency, between now and 2030, 55 percent of greenhouse gas mitigation potential lies in identifying and implementing energy efficiency opportunities.

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Energy efficient design and business competitive advantage

Improving energy efficiency in the design of buildings, industrial processes and equipment, manufactured products, and transportation vehicles is critical to helping businesses remain competitive by reducing operational costs and strategically positioning them for growing global markets.

The ANU Business School, through its Undergraduate Corporate Sustainability major, teaches the next generation of business leaders the potential of energy efficiency strategies to improve business competitive advantage.

ANU staff have contributed to a range of research projects over the last decade to better understand how to improve the energy efficiency of the design of engineered systems. For example, Dr Xiaolin Wang, from the Research School of Engineering, has successfully demonstrated the use of gas hydrate technology to turn air conditioners into cost-effective cold thermal storage systems. Effectively, this enables air conditioners to be used as a thermal battery, creating and storing cold gas when excess energy is available, and deploying the system at a later time for cooling.

ANU energy management systems lead to increased energy efficiency

ANU has expertise in research, design and implementation of effective energy management systems. The University has implemented and managed its own energy management system and energy efficiency strategy for close to a decade now. This has resulted in the ANU achieving significant reductions in energy usage.

A new development this year is the extension of data collection for the real-time monitoring of energy consumption of buildings on campus. In addition to the currently existing 500 meters, another 400 meters will be added by the end of the year. As reported by Energy Efficiency cluster member, Mark Pritchard (Facilities & Services Division), buildings with high energy use are targeted for energy efficiency measures. In the past two years,

Cluster Members:

Convenor: Dr Marnie Shaw Professor Xuemei Bai Dr Sid Chau Dr Grace Chiu Professor Denis Evans Professor Denis Evans Professor Weifa Liang Dr Adrian Lowe Dr Adrian Lowe Dr Chathurika Mediwaththe Mr Bartholomew Meehan Dr John (Jack) Pezzey Dr Digby Race Honorary Associate Professor Hugh Saddler Dr Xiaolin (Shannon) Wang Mr Tom Worthington

Mr David Glavas

Mr John Sullivan

Dr Xiaolin Wang has demonstrated the use of $\rm CO_2$ hydrate cold storge which acts like a thermal battery for air conditioning systems.

nine buildings have been targeted for increased energy efficiency. Combined, they have yielded an annual reduction of 655MWh of electricity and 3896MJ of gas.

The University energy management system has further improved energy efficiency through the replacement of cooling plants with in-house designed water cooling systems. The system makes use of Canberra's unique low humidity conditions to run centralised water-cooled systems at high efficiencies, resulting in a reduction of energy consumption in buildings by around 25 per cent. The replacement of these systems has yielded a further annual reduction of 809MWhr of electricity and 2234MJ of gas.

Energy for Development

Energy poverty, or the lack of access to modern energy services, is a global problem. Approximately 940 million people today are without access to electricity. Over three billion people are without access to clean fuels and technologies for cooking. The Sustainable Development Goals aim to reduce both figures to zero by 2030.

The Energy Change Institute's Energy for Development cluster was established in 2017 to bring together researchers working on energy and development issues from across the ANU. Energy research relating to consumption and economic development is conducted at the Crawford School of Public Policy, including through the Arndt-Corden Department of Economics (focused largely on Indonesia) and the Development Policy Centre (on the Pacific). Research on energy access is also undertaken at the Fenner School for Environment and the ANU College of Law. The ANU College of Engineering and Computer Science has an interest in design of appropriate technology.

Over three billion people are without access to clean fuels and technologies for cooking. The Sustainable Development Goals aim to reduce both figures to zero by 2030.

One of the highlights of 2018 was a policy forum on energy for development, which ECI convened as part of the 2018 Australasian Development Economics Workshop. Speakers discussed the implications for developing countries of the renewable energy transition, as well as challenges relating to the expansion of energy access.

ANU researchers published on a range of subjects relevant to energy for development in 2018. Dr Paul Burke, in research supported by an Australian Research Council Discovery Early Career Researcher Award (DECRA), published two papers on the effects of Indonesia's energy subsidy reduction program. Professor David Stern and Dr Paul Burke published research on the economic effects of electricity access and reliability, which will help policy-makers and aid agencies make decisions regarding investment priorities. Dr Matthew Dornan published a chapter in the Routledge Handbook of Small States on the unique challenges relating to power sector regulation in small island states. Edwina Fingleton-Smith published work on the implications of gendered household roles on energy expenditure and donor-funded energy access programs in Kenya.

Cluster Members: Convenor: Dr Matthew Dornan Associate Professor Sara Bice Dr Paul Burke Associate Professor Jane Golley Associate Professor Alastair Greig Professor Stephen Howes Professor Frank Jotzo Dr Arianto Patunru Dr Digby Race Professor Budy P Resosudarmo Professor David Stern

L to R: Zeba Anjum, Lynette Molyneaux, Andrew Blakers and Lorena Estigarribia at the 2018 Australasian Development Economics Workshop's policy forum on energy development.

Energy Regulation & Governance

The Regulation and Governance cluster of the Energy Change Institute brings together researchers concerned with questions of how the law can encourage, or impede, a rapid transition to a cleaner energy future. Poorly designed and/or administered frameworks of institutions, regulation and governance can represent a barrier to a rapid transition to clean energy. This group's research involves examining options for law reform, the record of implementation of various laws, as well as the interaction of different levels of law, policy and governance.

The group approaches these vital questions on several different scales - international, comparative and by examining Australian issues of law and policy at federal and state levels.

The group's active list of projects in the Asian region mean that it is well positioned to make a contribution to our Grand Challenge project *Zero-Carbon Energy for the Asia-Pacific*.

Japan Australia Energy Dialogue

Research into the energy future in Japan is of interest given Japan's active steps towards a hydrogen society, its shift away from nuclear energy post-Fukushima, and with its rapid uptake of solar energy since the passage of Japan's feed in tariff law. The Japan-Australia Energy Dialogue, funded by the Toshiba International Foundation (after an application lodged by James Prest) provided a high-level forum for energy scholars and policymakers from both countries. The first stage of the Dialogue was held in Tokyo at Keio University in September 2017, hosted jointly by the Law Schools of Chuo, Keio and Waseda Universities. Next, in March 2018, a two day workshop was held at the ACT Renewables Innovation Hub. This event was well attended by a mix of Commonwealth and ACT government officials, representatives of the Japanese Embassy, and researchers from more than five Japanese universities and think tanks. It was webcast live to participants in Japan and featured an excellent session on EV policy with representatives of Nissan and the EV Council.

Regulatory research: Biogas and Hydrogen

The need for greener gas networks is driving research interest in biogas and hydrogen. Funding from Energy Developments Ltd and the Department of Innovation was secured to conduct research into regulatory barriers to the expansion of the biogas sector in Australia.

The regulatory group has also been active within the ANU hydrogen research network, with funding from Global Power Generation Pty Ltd (a subsidiary of Union Fenosa), with the completion of a policy and law reform report on the role of hydrogen in the integration of electricity and gas networks.

International Energy Law

Professor Gunningham of Regnet commenced a Climate and Energy Finance project, "Harnessing financial markets and institutional investment to increase the penetration of clean energy in the Asia Pacific", funded by DFAT.

Cluster Members:

Convenor: Dr James Prest Associate Professor Sara Bice Dr Tim Bonyhady Dr Katherine Daniell Dr Christian Downie Professor Peter Drahos Professor Tom Faunce Professor Neil Gunningham Associate Professor Llewelyn Hughes Professor Andrew MacIntosh Dr John (Jack) Pezzey Dr Hedda Ransan-Cooper

The group's active list of projects in the Asian region mean that it is well positioned to make a contribution to our Grand Challenge project Zero-Carbon Energy for the Asia-Pacific.

He also completed an overview report on "Mobilising Climate Finance in Emergent Asia" (Anantharajah and Gunningham) and begun the first phase Fiji fieldwork looking to explore the potential of low carbon development, how this can be financed by the private sector, and leveraged by public funds and official development assistance. There is a particular focus on financing renewable energy, SME development and rural electrification.

Also at Regnet in 2018, Dr Christian Downie commenced a Discovery Early Career Researcher Award (DECRA) from the ARC, for the project "Who Governs Global Energy? The Role of Informal International Organisations". This project will produce new data and analytical tools for policymakers seeking to govern energy at the global level in the face of mounting challenges, including energy-related emissions.

Energy Sociology & Risk

The transition from fossil-fuel-based energy systems to a largely renewable energy future raises a host of social and political issues. This is particularly true for Australia – a country with enormous renewable energy potential, but with a history of fossil-fuel-intensive energy use, approaching 90% in the electricity sector.

Within ANU, researchers are working on topics that include fair and just energy transitions; the social impacts of climate change and the transition to zero carbon; energy-related human rights; social licence to operate issues; and social risk.

Key questions relating to risk include - How are risks associated with existing energy systems, and their alternatives, distributed? Why do some risks capture our collective attention more than others? How best can transformation in the consumption of energy be facilitated?

The Bruny Island smart battery project team won three awards including the Clean Energy Council's Community Engagement Award (2018.)

Sociology and Risk Research Cluster member Dr Hedda Ransan-Cooper was part of a smart battery project on Bruny Island, Tasmania, involving consumer-owned photovoltaic battery systems that simultaneously provide network support and consumer value. The success of the project was its ability to show that the technology worked on a live grid. Part of the project involved a number of household interviews to understand how energy users responded to the technology. The team presented their work at the All Energy Conference and highlighted the project in an article that appeared in The Conversation.

The Bruny Island project is a collaboration with Tasmanian Networks, Reposit Power, the University of Sydney and the University of Tasmania. The project team won three awards including the Clean Energy Council's Community Engagement Award (2018).

In October 2018 the Energy Change Institute hosted a symposium - Social Equity in the Energy Transformation. This symposium examined how the energy transformation will affect social equity, and whether the transformation process can be harnessed to reduce, rather than exacerbate, social inequities in Australia. The event brought together experts from government, business, community groups, think-tanks and academia to discuss challenges and strategies for one of the most important social transformations of modern times.

Cluster Members: Convenor: Associate Professor Sara Bice Dr Grace Chiu Dr Rebecca Colvin Dr Katherine Daniell Associate Professor Alastair Greig Emeritus Professor Andrew Hopkins Associate Professor Llewelyn Hughes Dr Digby Race Dr Hedda Ransan-Cooper

Photo credit: Moss Community Energy Launch, flickr

Energy Storage and Recovery

Short-term energy storage is increasingly important to smooth out peaks of high energy demand and low energy supply. This cluster is made up of seven main research themes:

Pumped hydro energy storage (PHES)

Andrew Blakers, Matthew Stocks and their team are investigating the potential of energy storage via off-river PHES which are easier and cheaper to construct than large hydro-electric dams.

Fuel cell research

Fuel cell research focuses on the development of new plasma processing techniques to make fuel cell components and the electrical testing of fuel cell assemblies. Electrode development and testing commercially available integrated manufacturing systems include some of the research carried out in the Space Plasma, Power and Propulsion laboratory, Research School of Physics and Engineering

Solar thermal energy storage

Energy storage technologies based on sensible, latent, and chemical reaction heat for solar applications are being developed by Wojciech Lipinski's team in College of Engineering and Computer Science. Hydrogen storage at ambient environment is also being developed by Yun Liu, Zongyou Yin, and Antonio Tricoli in collaboration with Terry Frankcombe (ADFA/UNSW).

Hydrogen energy generation

Chennupati Jagadish, Hoe Tan and Siva Karuturi's team are developing multi-layered III-V compound semiconductors to enhance light absorption for direct solar water splitting for hydrogen production.

Ronald Pace, Rob Stranger and Takuya Tsuzuki are working to develop a new 'Bubble Free' Electrolysis Technology which is expected to convert water into the clean fuel, hydrogen.

The team at the Research School of Engineering, including Kylie Catchpole, Siva Karuturi, Yimao Wan, Fiona Beck will work on Low-Cost Perovskite/Silicon Semiconductors Integrated with Earth Abundant Catalysts for Efficient Solar Hydrogen Generation and address one of the most significant challenges for hydrogen production: the development of efficient, stable and cheap solar water splitting systems.

Antonio Tricoli and Yun Liu will develop the technology for low cost, robust, high activity water splitting electrodes.

Energy nanomaterials

Energy nanomaterial research concentrates on the liquid-state processing of electroceramics for energy applications by creating novel nanostructured ceramics with high functionality. New directions for energy storage include developing nanostructured electrode material. Positive results would be a significant leap for storage technology of cheap systems that store huge amounts of energy and charge/discharge it very quickly.

Cluster Members:

Convenor: Professor Yun Liu Dr Lachlan Blackhall Professor Andrew Blakers Professor Rod Boswell Dr Evan Franklin Dr Peter Kreider Professor Weifa Liang Professor Wojciech Lipinski Dr Adrian Lowe Dr Matthew Stocks Associate Professor Takuya Tsuzuki Professor Raymond Withers Dr Zongyou Yin

Functional Materials and Devices for Energy Storage

Materials chemistry research for energy conversion and storage is carried out at the Research School of Chemistry and lead by Yun Liu and Zongyou Yin. They have achieved a major research breakthrough in the development of a new material that can store large amounts of energy with very little energy loss and a fast response to instability of energy generation. Applications include renewable energy storage, electric cars, and defence and space technologies.

Battery storage

In addition to the research programs outlined here, a new \$8 million partnership with the ACT government saw the establishment of a new battery storage and integration research program in 2018, led by Lachlan Blackhall.

Energy-Water Nexus

The Energy-Water Nexus is active in the connections between water and energy in its many dimensions. Responding to climate change, meeting expanding energy demand and sustaining freshwater resources are three of the greatest challenges facing society. There are crucial and often unacknowledged linkages between policies intended to achieve each of these objectives.

Cluster members have been engaged in public engagement and advice, teaching and also research. A cluster highlight is the November 2017 Australian Council of Learned Academies (ACOLA) report 'The Role of Energy Storage in Australia's Future Energy Supply Mix' that was co-authored by Professor Quentin Grafton, and who was also on the Expert Working Group representing the Academy of the Social Sciences in Australia (ASSA). This report examined the opportunities, benefits, costs and risks of all forms of energy storage for the electricity grid, including pumped hydro. Quentin also presented at the World Bank in Washington DC in March 2018 his findings from a study of the India's groundwater-energy nexus. The presentation went live across several of the World Bank's global offices and this research responds to an unfolding groundwater crisis in India's northwest.

Responding to climate change, meeting expanding energy demand and sustaining freshwater resources are three of the greatest challenges facing society.

Cluster member Associate Professor Jamie Pittock, is active in the Mekong region and his work is supported by WWF International. In 2018 Jamie published a paper, with co-authors, entitled "The Mekong River: Trading off hydropower, fish, and food' in the journal, Regional Environmental Change that highlights critical trade-offs in the region.

Cluster Members: Convenor: Professor Quentin Grafton Dr Katherine Daniell Professor Stephen Dovers Dr Barry Newell Associate Professor James Pittock

Enhanced Oil & Gas Extraction

A major aim of this research cluster is to facilitate extraction of oil and gas reserves in the most optimal and sustainable manner. The goal is to reduce the emissions and costs associated with the industries and over the longer-term allow cleaner alternatives, such as gas, to displace coal-fired electricity.

The Department of Nuclear Physics, Research School of Physics and Engineering, at the ANU hosts the largest ion accelerator in Australia. The high energies provided by the 14UD accelerator allow Accelerator Mass Spectroscopy (AMS) measurements of the isotope ³⁶Cl at a sensitivity that is unparalleled around the globe. Measurements of ³⁶Cl provide useful insight into the large scale structure of oil and gas fields in a number of ways.

Researchers have been working for over a decade with many of the largest petroleum companies in the world to better understand the physics of fluid flows between grains in sedimentary rocks. These studies also contribute to improved understanding of the fundamental processes underpinning shale gas extraction and can help quantify the risks of environmental damage and fugitive CO, emissions.

Cosmic rays initiate nuclear reactions in the atmosphere to continuously produce trace quantities of the radioactive isotope ³⁶Cl. The atmosphere also contains stable chlorine isotopes derived from sea spray and re-mobilised terrestrial salts. This results in a characteristic ³⁶CI/CI ratio for a given location, and rain water that enters the groundwater system is thus labelled by the ³⁶Cl/Cl ratio. Radioactive decay of ³⁶Cl can then be used as a clock to date basin water residence times from a few thousand to a few million years, giving information on the source, origin and recharge rates of underground aquifers. In collaborations with the Queensland government Department of Natural Resources and Mines, and with researchers at CSIRO, the University of Queensland and the Queensland University of Technology we are currently using ³⁶CI AMS measurements to investigate and understand the hydrology of Australian coal seam gas prospects to allow optimal development of the gas extraction process.

Cluster Members: Convenor: Professor Mark Knackstedt Professor Tim Senden Professor Adrian Sheppard Professor Andrew Stuchbery Dr Stephen Tims

In the oil sector, the Department of Nuclear Physics has also had a long industry collaboration with Statoil of Norway (now Equinor) through its partner IFE (Institutt for Energiteknikk), and more recently with ResTrack (a spin-off company of IFE). Artificially produced ³⁶Cl (made in nuclear reactors) was injected in seawater into the oil-bearing strata at injection wells in the North Sea oil field. Brine accompanying oil from production wells in the vicinity was then analysed for ³⁶Cl content using AMS. The first appearance and subsequent time development of the ³⁶Cl signal provides information on the recoverable reserves, well-towell communication and on the oil field heterogeneity. The data obtained make a significant contribution to the efficiency and effectiveness of the oil extraction program.

Similarly, researchers in the Department of Applied Mathematics, Research School of Physics and Engineering, have been working for over a decade with many of the largest petroleum companies in the world to better understand the physics of fluid flows at the sub-millimetre scale (between grains in sedimentary rocks). These studies also contribute to improved understanding of the fundamental processes underpinning shale gas extraction and can help quantify the risks of environmental damage and fugitive CO₂ emissions. Much of the science and technology in this area is in common with that required for geologic storage of CO, and therefore research in this area overlaps with work done as part of ECI's Carbon Capture and Storage research cluster.

Fusion Power

Fusion is the process that powers the sun and stars. It has the potential to deliver effectively limitless, clean, base-load power for future generations.

ANU researchers, technologies and expertise are strongly linked into the next step burning fusion experiment, the International Thermonuclear Experimental Reactor (ITER). These linkages are enabled by an innovative collaborative agreement made in 2016 between the ITER Organisation and the Australian Nuclear Science and Technology Organisation (ANSTO), on behalf of all Australian scientists. The agreement enables the provision and exchange of research, data and scientific cooperation through projects, and participation of Australian experts in the International Tokamak Physics Activity (ITPA) and the ITER Science Fellow Network.

Two Schools of the ANU have fusion research activity: the Mathematical Sciences Institute, and the Plasma Research Laboratory of the Research School of Physics and Engineering. There is significant international collaboration in both schools, spanning the ITER international project, the W7-X superconducting stellarator (Germany), the KSTAR superconducting tokamak (Korea), the DIII-D National Facility (USA), the MAST tokamak (UKAEA) groups, the National Institute for Fusion Science (Japan), Princeton Plasma Physics Laboratory (USA), and the University of Texas, Austin (USA).

Fusion has the potential to deliver effectively limitless, clean, base-load power for future generations.

The Plasma Research Laboratory (PRL) performs research across a multitude of activities including plasma-material Mathematical Sciences Institute, ANU interactions, the study of 3D magnetic confinement systems, and the development of advanced remote sensing systems. PRL The Mathematical Sciences Institute hosts the Plasma Theory houses the MAGPIE I prototype device (MAGnetised Plasma and Modelling Group, who develop theory and models Interaction Experiment) developed for investigating the interaction describing high performance toroidally confined burning plasmas of plasma with materials, especially those potentially suitable for as well as stellarators. Fields of research include equilibrium fusion reactors. Currently, PRL is decommissioning the H-1 heliac physics, wave-particle physics and MHD stability, Bayesian and redeploying its considerable infrastructure in support of the inference from complex fusion data sets, and toroidal magnetic high power MAGPIE II device. This MAGPIE II machine will help confinement experiments. The group is embedded in a research maintain a frontline Australian research capability in fusion and environment that includes collaboration with computational plasma physics, nanotechnology, material science, and atomic mathematics, astrophysics, and computer science research. and molecular physics. In recent significant developments, highly In 2018, the group, in collaboration with Princeton University. prized port space on ITER has been reserved for a novel optical imaging system conceived and developed at the APFRF..

Cornell University, Max Planck Institute for Plasma Physics Greifswald, New York University, Columbia University, University of Marvland, University of Texas (Austin), Warwick University and the University of Colorado, Boulder, won a prestigious Simons Foundation grant "Hidden Symmetries and Fusion Energy". The project, valued at \$US2m per year for four years and led by Princeton University, aims to develop the optimal design principles of the fully 3D stellarator class of toroidal magnetic confinement devices

Cluster Members: Convenor: Associate Professor Matthew Hole Emeritus Associate Professor Boyd Blackwell Dr Cormac Corr Emeritus Professor Bob Dewar Emeritus Professor John Howard

ITER, France, reaches a 50% construction milestone (25 July 2018)

The Plasma Research Laboratory (PRL), ANU

Nuclear Science

Nuclear Science at ANU operates the premier laboratory in Australia for accelerator-based research in nuclear physics, providing and developing experimental facilities for local staff and external users.

The Heavy Ion Accelerator Facility is used for educational training over a wide range of basic and applied research. The research draws on a suite of techniques and instruments, and on the flexibility of the Heavy Ion Accelerator itself.

The ANU's Department of Nuclear Physics promotes and hosts evidence-based discussions on the nuclear fuel cycle, including nuclear waste management.

Research areas include fundamental nuclear and quantum physics as well as applications of accelerator-based techniques. Applications focus particularly on accelerator mass spectrometry methods, and range from extending our understanding of the properties of advanced fuels for Generation IV nuclear reactors, to climate change monitoring, the determination of groundwater flows, and environmental tracing of nuclear discharges via ultrasensitive measurement of rare isotope abundances.

The Heavy Ion Accelerator Facility supports many active national and international research collaborations. It is operated as a National Facility, with merit-based access via collaborative agreements.

In relation to nuclear energy, the ANU's Department of Nuclear Physics promotes and hosts evidence-based discussions on the nuclear fuel cycle, including nuclear waste management. It also has an important role in training personnel concerned with Australia's national and international roles in nuclear safety, security and nonproliferation.

Cluster Members: Convenor: Professor Andrew Stuchbery Professor Keith Fifield Professor David Hinde Honorary Associate Professor Tony Irwin Dr Greg Lane Dr Stephen Tims

Inside the Heavy Ion Accelerator.

Renewable Fuels

Research into renewable fuels (formerly known as biofuels) at ANU takes place at the Research School of Chemistry , the Research School of Biology and the Research School of Engineering.

At the Research School of Biology, the research has a strong focus on plant science. Research is conducted by world leading researchers in photosynthesis, plant physiology, biotechnology and high throughput analysis.

The Solar Thermal Group, at the Research School of Engineering, has two major activities in relation to solar fuels production, both of which are taking place under the ASTRI (Australian Solar Thermal Research Initiative) program.

The latest results suggest...algaederived gasoline and diesel (via gasification followed by Fischer-Tropsch synthesis) can be produced for a cost as low as \$3.50 per litre.

The first is an investigation into the production of solar biofuels from microalgae via gasification in supercritical water. A labscale test rig has been constructed and is currently being used for experimental testing. In parallel, a range of technoeconomic process evaluations have been conducted, with the latest results suggesting that algae-derived gasoline and diesel (via gasification followed by Fischer-Tropsch synthesis) can be produced for a cost as low as \$3.50 per litre, providing materials and process variability issues can be addressed. Methanol synthesis has also been investigated as a downstream process.

The second activity is an investigation into synthesis gas production via CO_2 and H_2O splitting using metal oxide based thermochemical redox cycles. An experimental prototype has been constructed and will be tested shortly in the ANU High-Flux Solar Simulator.

The functional materials group at the Research School of Chemistry, led by Dr Zongyou Yin, published research describing a Na-ion battery, electrocatalytic oxygen evolution reaction, electrocatalytic hydrogen evolution reaction, photoelectrochemical water splitting, solar water evaporation distillation and plasmonic water splitting.

Cluster Members:

Convenor: Professor Colin Jackson Associate Professor Michael Djordjevic Professor Graham Farquhar Dr Carsten Kulheim Professor Wojciech Lipinski Associate Professor Ron Pace Dr Dean Price Dr John Pye Associate Professor Antonio Tricoli Dr Zongyou Yin

Smart Grid

In the future, the electricity grid will feature millions of intermittent and distributed generation sources, support many electric vehicles, and give greater incentives and control to consumers to optimise energy usage. It will require an unprecedented level of automation, to self-manage, self- reconfigure and self-heal. This vision challenges the human-controlled, top down management style of traditional grids, which relies on the existence of a few predictable and adjustable fossil fuel generators.

The ECI Smart Grid Cluster conducts research into the use of control, communications, optimisation, artificial intelligence, machine learning, data and analytics to support future energy systems, in areas such as grid integration of renewables and storage, microgrids, energy price and solar forecasting, demand response, and home and building energy management.

The future electricity grid calls for a fundamental paradigm shift in the way power systems are planned and operated, underpinned by a new generation of communication, control, data analytics, and optimisation technologies.

Battery Storage and Grid Integration Program

The new Battery Storage and Grid Integration Program, instituted in April 2018, is jointly hosted within the ANU by the Research School of Engineering and the Research School of Chemistry. The program undertakes activities related to the development, integration, operation, and optimisation of energy storage in electricity grids, and electricity markets, globally.

Cluster Members: Convenor: Professor Sylvie Thiebaux Dr Lachlan Blackhall Dr Jamie Bright Dr Sid Chau Dr Nicholas Engerer Dr Evan Franklin Dr Dan Gordon Dr Hassan Hijazi Professor Weifa Liang Dr Chathurika Mediwaththe Dr John Pye Dr Paul Scott Dr Marnie Shaw Dr Igor Skryabin Dr Kerry Taylor Dr Guanglei Wang

Of particular relevance to the Smart Grid Cluster, the devices, optimisation and control stream undertakes research and development of distributed optimisation and control capabilities (both hardware and software) to allow the effective and efficient operation of distributed energy resources, including battery and energy storage.

The data and analytics stream progresses state-of-the-art modelling, forecasting and prediction that is critical to the effective operation of energy storage capabilities in the electricity system and their participation in energy, ancillary and network services markets.

The Battery Storage and Grid Integration Program is funded by the ACT Government and the Australian National University.

Consumer energy systems providing cost-effective grid support (CONSORT)

CONSORT, an ARENA funded project, which commenced in April 2016, has resulted in the successful development and deployment on Bruny Island, Tasmania, of novel algorithms to automatically coordinate consumer-owned PV-battery systems to simultaneously provide network support and consumer value.

Building on expertise in optimisation and scheduling for smart grids within the ANU's Research School of Computer Science, the deployed system has led to a reduction of approximately 30 per cent in the use of backup diesel during holiday usage peaks, and has completely prevented the use of diesel on at least one occasion.

The project has been awarded the Electric Energy Society of Australia's (EESA) Energy Project of the Year (2018), the Clean Energy Council's Community Engagement Award (2018), and the Engineers Australia's Tasmanian Engineering Excellence Award (2018).

This project is a collaboration with Tasmanian Networks, Reposit Power, the University of Sydney and the University of Tasmania.

Demand-side management through community aggregation of distributed energy resources

This research project, based in the Research School of Engineering, is developing community market models for smallscale (e.g. a small residential community) electricity demandside management, using community energy storage systems and rooftop PV power generation. Electricity demand-side management plays an essential role in maintaining reliable grid operation with the rapid increase of electricity demand.

The project has developed algorithmic solutions to economically operate community energy storage systems with user-owned solar power generation which reduce peak electricity demand while delivering economic benefits to users.

Solar Photovoltaics

100% renewable energy futures

Solar Photovoltaics (PV) and wind energy now constitute 60 per cent of global annual net new generation capacity additions and effectively 100 per cent in Australia. They are growing fast enough to make deep cuts in global emissions by 2030. Deep electrification of energy services allows renewable electricity to address all the energy-related greenhouse emissions, which amount to 80 per cent of the total. It is difficult to see any timely solution to climate change that does not involve solar (and wind) doing most of the heavy lifting.

Our research shows that Australia can transition smoothly to 100 per cent renewable energy while retaining reliability of supply. Electricity from PV and wind is now cheaper than from newbuild fossil fuel power stations, and will soon fall below the cost of electricity from most existing coal power stations. Support from pumped hydro energy storage, batteries and strengthened interstate power lines facilitates a highly reliable renewable energy grid. Our work has shown that Australia has a vast number of excellent pumped hydro sites.

Net new global generation capacity additions in 2015 and 2017. PV is growing rapidly whilst the other generation technologies have negligible growth in annual net new deployment.

Electricity from PV (and wind) is now cheaper than from newbuild fossil fuel power stations, and will soon fall below the cost of electricity from most existing coal power stations.

Passivated contacts

The implementation of passivating contact has shown a great potential for approaching the practical efficiency limit of approximately 27.5 per cent for silicon solar cells. Passivating contacts allows the selective transport of electrons and holes towards the cell's terminals restraining the losses in the metal and silicon contacted areas. Recently, ANU researchers have developed 24.7 per cent efficiency silicon solar cells with such passivating contact technology. Supported by ARENA, ANU researchers are working on the development of industrial scaled passivating technologies to manufacture high efficiency industrial silicon solar cells by collaborating with the world's leading photovoltaic manufactures.

Silicon Solar Cells

The Silicon photovoltaic group is actively progressing technologies for high-efficiency mono-junction Si solar cells. Efficiencies exceeding 24.7 per cent was achieved on two different cell technologies, namely the Interdigitated Back Contact (IBC), and Passivated Emitter Localised Rear Contact (PERL) design. These improvements are the culmination of the progress in numerous fundamental aspect of the Si photovoltaic device such as understanding of impurity gettering, deactivation of crystal defects, improvement in passivated contacts, advancement in film deposition technology as well as in optical and 3D device simulations. Development of high-efficiency baseline devices forms the backbone of Si photovoltaic research, as it is the test bed for exciting new technologies, and directly supports the development of high-efficiency tandem solar cells.

Perovskite Solar Cells: Technology and Practices

Authors: Kunwu Fu, Anita Ho-Baillie, Hemant Kumar Mulmudi, Pham Thi Thu Trang.

This comprehensive handbook provides a broad and overall picture of perovskite solar cells. It covers up-to-date research in the field of perovskite photovoltaics - a fast trending branch of the thin film photovoltaic generation.

Perovskite solar cells

Solar cells based on perovskite materials are generating much attention and excitement due to the excellent solar cell efficiencies that have been demonstrated, as well as the fact that these cells possess many properties that make them highly attractive for large scale photovoltaic applications. Researchers at ANU have made significant improvements in a number of areas, including improved device stability and higher device efficiencies. They demonstrated best-in-class efficiencies of 26.4% and 22.5%, respectively, for two different types of perovskite-silicon 'tandem' solar cells that combine the advantages of silicon and perovskite technologies. The researchers also developed improved models to allow a more precise understanding of loss mechanisms in perovskite cells, which will aid in further improving their performance in the future.

Cluster Members:

Convenor: Professor Andrew Blakers Dr Fiona Beck Dr Kate Booker Professor Kylie Catchpole Professor Rob Elliman Dr Nicholas Engerer Dr Marco Ernst Dr Kean Chern Fong Associate Professor Lan Fu Professor Chennupati Jagadish Dr Siva Karuturi Dr Ziyuan Li Dr Daniel MacDonald Dr Hemant Kumar Mulmudi Dr Matthew Stocks Dr Sachin Surve Dr H. Hoe Tan Dr Yimao Wan Associate Professor Klaus Weber Dr Thomas White

Solar Thermal

The Solar Thermal Group investigates processes for the capture and conversion of solar energy in the form of heat.

The activities range from development of concentrating solar power (CSP) collector and energy storage technologies, to techno-economic assessments of novel processes to produce fuels and refined metals, to the role of CSP in the electricity network, to development of new highabsorptivity absorber coatings and characterisation of hightemperature thermochemical energy storage materials, and fundamental investigations of convection and radiative thermal transport phenomena.

The group also operates a new 45 kWe high-flux solar simulator and several other smaller pieces of high-temperature labscale apparatus. Together, these facilities and our associated analytical and computational capabilities make the group wellplaced to contribute to advancing the adoption of CSP as a key commercial technology for dispatchable renewable electricity, while also investigating next-generation applications to industrial processes such as hydrogen and iron and steel production. The group interacts regularly with a range of international commercial and research institution partners and participates in several large international collaborative programs.

The group is comprised of over 30 members under the leadership of Professor Wojciech Lipinski, including 9 academics, 1 research officer, 3 adjuncts and more than 20 higher-degree research students.

Research highlights

- > Pioneering analysis of the effects of thermal stresses in solar thermal receiver tubes, which allow CSP systems to be designed closer to material limits and achieve higher performance at lower cost.
- > Fabrication of a next-generation 'bladed' CSP receiver is currently underway after an extensive process of analysis and design. Testing will be taking place at CSIRO in Nov-Dec.
- > An extensive analysis of a options for solid-gas thermochemical energy storage options has been conducted, as a part of the search for future low-cost energy storage technologies.
- > Widely-cited review papers have been published on dish and heliostat technology, chemical processes using CSP, and on the techniques of modelling solar thermochemical reaction systems.

Projects

> Eight current ARC and ARENA projects are ongoing, including: a major role in the \$87M Australian Solar Thermal Research Inititative (ASTRI, with 6 other Australian partners). a prestigious ARC Future Fellowship (Lipinski), two ARC Linkage projects, two large (>\$1.3M) ARENA projects, and two ARENA International Engagement Program grants.

Cluster Members:

Convenor: Dr John Pye Dr Joe Coventry Dr Peter Kreider Dr Apurv Kumar Professor Wojciech Lipinski Dr Adrian Lowe Associate Professor Antonio Tricoli Dr Mahesh Brahmadesham Venkataraman Dr Xiaolin (Shannon) Wang Adjunct Professor Alan Weimer Dr Vincent Wheeler

ANU Solar Thermal Big Dish

- > A new ARC Linkage Project was granted in 2018 "Multi-scale engineering of durable absorber coatings for solar thermal power". Industry partners are Nano Frontier Technology and Vast Solar; CIs are Coventry, Lipinski and Tricoli. The project aims to advance the stability and efficiency of hightemperature absorber coatings for CSP, including low-cost fabrication/application methods.
- > Commenced in October 2018, the group is active in two new US-led projects with funding from the US Department of Energy (DOE), "Gen 3 Particle Pilot Plant (G3P3): Integrated High-Temperature Particle System for CSP" and "The Liquid-Phase Pathway to SunShot". Both projects aim to identify and develop next-generation pathways towards CSP at a levelised cost of 0.06 USD/kWhe, and involve large international consortia.

Industry Linkages

- > Vast Solar (Forbes, NSW), on solar field characterisation, receiver coatings and heliostat design.
- > Nano Frontier Technologies (Tokyo, Japan), on high-temperature selective coatings to increase receiver performance.
- > Solinova (Pirassununga, Brazil) and SunriseCSP (Canberra), on a customized cavity receiver design for the SMILE project with partners DLR (Germany).

Sustainable Transport

Transport is the second largest source of carbon emissions in Australia after electricity production. The transport sector will need to change significantly for Australian and international greenhouse emission targets to be achieved.

Sustainable Transport Policy

Research within the Crawford School of Public Policy involves examining the policy settings required to achieve a sustainable transport sector. A particular focus is given to policies to encourage the adoption of efficient and low-carbon transport technologies. Ongoing research includes identifying factors that affect the fuel efficiency of aircraft fleets. Work is also being undertaken on the effects of fuel prices on road transport outcomes such as vehicle choices, fuel use, emissions, traffic congestion, and road safety. This research is international in scope.

In 2018 Dr Paul Burke published a study in Economic Papers that estimated the effects of macro-level factors on the number of road deaths in Australia. The research found that the collapse in the world oil price in late 2014 made a material contribution to the subsequent increase in Australia's road death toll in the years 2015 and 2016. The research informed a submission to Australia's Inquiry into Progress Under the National Road Safety Strategy 2011-2020.

In 2017, Paul Burke and colleagues published a study on the effect of Indonesia's fuel subsidy reforms on traffic jams on Electric vehicles toll roads in Jakarta and elsewhere in the country. The paper, published in Transportation Research Part A: Policy and Practice, The coming shift to light electric vehicles will dramatically change found that episodes of fuel subsidy reduction led to a slowing in the energy landscape. While much more energy efficient, electric traffic growth. It was concluded that a history of subsidised fuel is vehicles will increase electricity consumption. The location and one of the factors that has contributed to Indonesia's notoriously timing of electric vehicle charging could lead to increased stress gridlocked traffic. Dr Burke followed up with a piece in The on the transmission and distribution systems. Jakarta Post which made the case for fuel excise rather than fuel subsidies, based on fiscal, environmental, and transport-Electricity will be the easiest sector management justifications.

Renewable Energy for Transport

The 100% Renewable Energy group in the Research School of Engineering researches the deployment and integration of renewable energy working towards carbon-neutrality throughout Australia's economy. Electricity will be the easiest sector to reduce emissions through use of renewable power. As electricity emissions approach zero, electricity is likely to be the primary enabler for reduced transport emissions through electrification of transport.

The transition to electric vehicles can have significant detrimental Liquid fuels have high energy density compared to batteries. Air impact on the electricity network if it is not well managed. travel and heavy transport (ships, long haul trucks) will therefore Based on Australian Bureau of Statistics fuel use figures, the be difficult to electrify directly. Synthetic fuels can be produced electrification of land transport should increase electricity demand from electricity through reactions driven from hydrogen and the by 33 per cent. Using real trip data recorded by NSW, different capture of carbon dioxide enabling conversion of renewable charging strategies for electric vehicle users were evaluated. electricity to transport fuels. Unmanaged charging when users arrived home increased wholesale electricity costs by around 20 per cent compared to modest increases (few percent) when charging was distributed to

Cluster Members: Convenor: Dr Matthew Stocks Professor Andrew Blakers Dr Paul Burke Dr Sid Chau Dr Grace Chiu

Professor David Stern

different times, particularly to align better with the solar resource. Incentives for vehicle owners to charge at optimal times will therefore help to manage the demand increase.

to reduce emissions through use of renewable power. As electricity emissions approach zero, electricity is likely to be the primary enabler for reduced transport emissions through electrification of transport.

Synthetic fuels

ANU ENERGY MASTER PLAN

Wind Energy

Research in the Wind Energy research cluster at the ANU covers a wide range of wind assessment, wind development and renewables integration topics.

Examples include legal aspects of wind energy development, aspects of environmental management, sociology, community psychology and social impact assessments such as health impacts of wind farms, international wind prospecting and renewables integration of hybrid wind, solar and storage projects. Research is complemented by Wind Energy, a course available to students in the Master of Energy Change and Climate Change degrees and Physics, Engineering and other ANU undergraduates.

In the two years since its inception, the Wind Energy course has doubled its enrolments (more than 50 students) and continues to be popular with those interested in a broad range of wind energy development topics ranging from the political environment through to the technical and physics aspects of wind energy. The course takes students through the fundamentals of wind generation, modelling and measuring wind resources, and procurement and contracting. It culminates with a major project that sees students choose the location for and design their own wind farm, starting from prospecting at a regional scale through to detailed site modelling and costing.

The course is industry led by Windlab with multiple presentations by Dr Nathan Steggel, Dr David Osmond and Dr Keith Ayotte. These are complemented by specialised presentations from ANU lecturers Dr Horst Punzmann (wind measurement), Dr Liz Hanna (health effects) and Dr James Prest (environmental and natural resources law) as well as industry representatives from Vestas and Ecology Partners.

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Research at the WindScape institute, an ECI partner, continues to revolve mainly around real-world integration of utility-scale renewables onto the national electricity grid underpinned by operational data from projects under management by Windlab's asset management business. The leading efforts in this area are centred around short term (5-minute ahead) and medium-term (1-48 hours) wind and generation forecasts that are based on computational weather/wind modelling and recent advances in machine learning algorithms.

Cluster Members:
Convenor: Dr Horst Punzmann
r Rebecca Colvin
r Elizabeth Hanna
ssociate Professor Andy Hogg
r Frank Mills
r James Prest
rofessor Michael Shats
r Igor Skryabin
r Nathan Steggel
r Hua Xia

Students of the Wind Energy Course visiting Capital Wind Farm, 2018

Recent social studies by Dr Rebecca Colvin regarding community conflict around wind energy included the publication of a teachable case study on the impact of using a community vote as a decision-making tool. Dr Colvin has presented her research related to community engagement at the Canberra Writers Festival 2018 and is engaged in media outreach.

600 ANU-invented 'sliver-cell' solar panels have been installed on the National Computational Infrastructure building at ANU

Energy Master Plan

This year will see the finalisation of the ANU Energy Master Plan (EMP) in parallel with the Heritage Master Plan and the overarching Campus Master Plan. In a unique partnership, the ECI has joined with the ANU Facilities and Services Division (F&S) to create a blueprint for an energy efficient, low-carbon, leastcost campus, working with the EMP consultants Arup.

The ECI and F&S has formed expert teams on solar generation, smart grids, power engineering, heat storage and management, energy pricing/contracts/regulation, carbon accounting, and water sustainability. We have also enlisted the assistance of a group of Master of Energy Change students to contribute to analysis that underpins the EMP, funded by a \$50,000 grant from industry partner CWP Renewables.

The Energy Master Plan will:

- > involve a unique, research-led partnership of expertise between the ECI and F&S
- > create a living test-bed providing a high-profile environment for research and education, including pilot demonstrations of ECI research ideas
- > include gas, water, thermal and electricity energy vectors, involving energy savings, efficiency, generation and storage
- > create an ANU electricity micro-grid that will provide demand management capability for the ACT from the Territory's largest customer.

As the plan develops, we will take advantage of opportunities to include ECI research initiatives. An example was the installation of almost 300 kilowatts of 'sliver cell' solar panels on ANU roofs - a home-grown technology developed here at ANU. This is just one example of the research-led philosophy of the EMP.

The Campus Master Plan is scheduled for delivery at the end of 2018.

GRAND CHALLENGE

Zero Carbon Energy for the Asia-Pacific Grand Challenge wins \$10M

Research into a new export industry to deliver cheap, clean energy for Australia and the region has received \$10 million in funding as part of the ANU's Grand Challenges program.

The Grand Challenge Scheme invests in transformative research to make the impossible possible. In its second year, the scheme seeks to bring new perspectives to the most pressing challenges facing society.

"This year's Grand Challenge winning project - to deliver zerocarbon energy to Asia Pacific - is a blueprint for the prosperity of Australia, and our region," ANU Vice-Chancellor Professor Brian Schmidt said.

"I'm really excited about this project because it will deliver exactly what the world needs at this juncture in our history: big thinking, practical solutions, and collaboration across research, industry and the community."

The Zero-Carbon for Energy for the Asia-Pacific project will provide research underpinning the development of major export industries based on renewable energy, including direct electricity export, hydrogen-based fuels, and zero-carbon mineral extraction and processing. Importantly, the research will focus on how a transformation of Australia's energy exports can be achieved in a timely, fair and sustainable manner.

"Our Grand Challenges scheme tasks our immensely talented researchers to think of ways to tackle the toughest problems," Professor Schmidt said.

"It is about going out and making a difference for our country and that's our role as the national university" said ANU Vice-Chancellor Professor Brian Schmidt.

The winning team is led by Professor Ken Baldwin from the ANU Energy Change Institute

L to R: Grand Challenge team members Dr Paul Burke. Prof Kylie Catchpole and Dr Emma Aisbett delivered the winning pitch.

Grand Challenge Vision

The ECI's Grand Challenge (GC) - Zero-Carbon Energy for the Asia-Pacific - recognizes that Australia is a renewable-energy, resource-rich nation, whose immediate neighbours in the Asia-Pacific will account for two-thirds of the world's energy demand growth in the coming decades. Decarbonizing that additional energy use and cutting existing emissions from the region are essential if the world is to have any chance of meeting its goals for limiting climate change. In a rapidly decarbonizing world, Australia's carbon-based exports will soon have to be replaced by zero-carbon embedded energy exports in order to maintain our role as an energy superpower.

The Zero-Carbon Energy for the Asia-Pacific team is a truly interdisciplinary team with researchers from five of the ANU Colleges (College of Science, College of Asia and the Pacific, College of Law, College of Engineering and Computer Science and College of Arts and Social Sciences).

The project includes a number of external collaborators including CWP Renewables, a leading renewable energy developer, that has established a consortium to develop the Asian Renewable Energy Hub (AREH), in north-western Australia. The AREH is on track to become the second-largest power plant in the world. Other external partners include the ACT Government, Evoenergy (formerly ActewAGL), the Australian Renewable Energy Agency (ARENA) and the Australia-Indonesia Centre headquartered at Monash University.

65% of energy growth Asia-Pacific

Our GC will investigate four socio-technological pathways to Zero-Carbon Energy for the Asia-Pacific that integrate social, legal, economic, political and technological solutions. The first two pathways involve reducing the carbon content of electricity consumed in the region via:

- 1. Large-scale renewable electricity generation for NW Australia, and also for export via subsea cable.
- 2. Policies and frameworks for renewable electricity generation and use in other Asia-Pacific countries.

The other socio-technological pathways embed our zero-carbon energy in exports via:

- 3. Large-scale renewable electricity production of hydrogen-rich fuels and other products.
- 4. Large-scale renewable refining of metal ores (especially iron).

Our research on each of these four pathways will be conducted along 3 research lines:

- > Stakeholder & Impact: What are potential impacts on stakeholders and communities (particularly Indigenous)? How can the outcomes support the UN Sustainable Development Goals? How can we best engage groups to maximise positive outcomes? Which gatekeepers could block impact?
- > Techno-economic: What is the techno-economic potential of the available and emergent technologies? How do we maximise their performance? Can they compete in the relevant markets in the timeframe required? How do technologies compare on environmental and social criteria?
- > Policy & Governance: What role might policy, legal and institutional ('governance') frameworks have in supporting or inhibiting the transition via each pathway? What role can governance play in optimising the sustainable development impacts of a transition along each pathway?

For more information on the Zero-Carbon Energy for the Asia-Pacific Grand Challenge, please contact:

Dr Emma Aisbett Transdisciplinary Research and Collaboration Leader

E emma.aisbett@anu.edu.au

PUBLIC POLICY

The ECI continues to engage in the development of public policy through its extensive relationships with government departments and agencies.

This year's public policy highlights included:

International

Coal transitions in Australia: Preparing for the looming domestic coal phase-out and falling export demand. Co-authored by Professor Frank Jotzo and Mr Salim Mazouz with collaborators at the University of Melbourne. This report explores pathways, implications and policy options for Australia to move beyond domestic coal use during the next two decades, as its old coal plant fleet continues to age and renewable energy becomes more competitive. It also highlights the need to prepare for growing downside risks to its coal export sector as market fundamentals shift in the Asia-Pacific region.

The report and a related paper led by Paul Burke "Closures of coal-fired power stations in Australia: local unemployment effects", are part of Coal Transitions, an international research project consisting of national experts in China, India, South Africa, Poland, Australia and Germany. The research project explores options for their countries to implement economically feasible and socially acceptable coal transition strategies that are consistent with the goals of the Paris Climate Agreement.

Federal and State Government

Professor Andrew Blakers and his team continued to influence public policy with their work on pumped hydro cited in a number of national and state-based reports including:

> Numerous references in the Climate Council report "Fully Charged: Renewables and Storage Powering Australia" https://www.climatecouncil.org.au/battery-storage-2018 (February 2018)

- > Pumped hydro sites, Figure 11, Integrated System Plan Consultation For the National Electricity Market http:// aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_ Forecasting/ISP/2017/Integrated-System-Plan-Consultation. pdf (December 2017)
- > NSW Chief Scientist's Energy Security Taskforce's Report; references to 100% Renewable Energy paper and the Pumped Hydro Atlas, http://www.chiefscientist.nsw.gov. au/_data/assets/pdf_file/0019/136711/171219-MASTER-NSW-Energy-Security-Taskforce-report-FINAL-SIGNED.pdf (December 2017)

Professor Frank Jotzo, Mr Salim Mazouz, Honorary Associate Professor Hugh Saddler and Dylan McConnell (University of Melbourne) provided a submission to the Energy Security Board's National Energy Guarantee Draft Design Consultation Paper in March 2018.

The Energy Change Institute and the Climate Change Institute made a joint submission to the ACT Government's Climate Change Strategy, April 2018.

The RE100 group (Renewable Energy - 100 percent) and Dr James Prest from the ANU College of Law both provided submissions to the Select Committee on Electric Vehicles. Dr Matthew Stocks and Dr James Prest were invited to present their submissions to the Committee on 17 August 2018.

Professor Ken Baldwin, Professor Andrew Blakers and Dr Matthew Stocks analysed data from the Clean Energy Regulator that showed the Australian renewable energy industry will install more than 10 gigawatts of new solar and wind power during 2018 and 2019. If that rate is maintained, Australia would reach 50% renewables in 2025. September 2018.

Renewable Energy Capacity Install Rates

Individual contributions

ECI researchers contribute to public policy development through The University has a major role in providing expertise to their individual research expertise as part of their everyday governments and the wider community through its Public Policy Fellows program in which the ECI is a major player, contributing 5 activities - particularly in the disciplines of economics, law, sociology and policy. Amongst many individual achievements Public Policy Fellows throughout the year, ECI researchers contributed to the following Currently the ECI has 5 Public Policy Fellows: areas of public policy:

- > Professor Andrew Blakers Submission to ACT
- Under the National Road Safety Strategy 2011-2020, March 2018
- Council inquiry into electricity prices, September 2017

ANU Public Policy

Crawford School of Public Policy

EVENTS

The ECI organised and hosted many public events this past year, ranging from public lectures by eminent speakers of global standing, to seminars and discussions of a technical nature, engaging experts and practitioners in the field of energy change in discussions around science, technology and policy.

More information about these events can be found at energy.anu.edu.au/news-events

Our largest ever gathering for an 'Energy Conversations' event: The Future of Sustainable Transport. Held at the ACT's Renewable Innovations Hub.

Flagship events

ANU Energy Update 2017 29 November 2017

The annual ANU Energy Update brought together Australian researchers, policymakers, industry and members of the public to provide an update on the latest world energy trends from the International Energy Agency World Energy Outlook. Dr Alan Finkel, Australia's Chief Scientist delivered a keynote speech on implementing the National Electricity Market Review.

2017 ACT Government/ANU Solar Oration: The Australian Energy Transition 29 November 2017

Australia is in the midst of a major energy transition, from fossil fuels to renewable energy. Ms Audrey Zibelman, CEO of the Australian Energy Market Operator (AEMO), discussed the intersection of the rise of renewables, grid stability and emission reductions.

ECI Open Day 30 October 2017 and 19 June 2018

The annual ECI Open Day showcased the latest in energy research at ANU to key stakeholders, with ECI participants and industry collaborators giving presentations on their work.

Meetings

ECI Annual Business Meeting 6 April 2018

The ECI Annual Business Meeting is an opportunity for ECI members to participate in setting the directions of the ECI over the coming year. This year Mr Shane Rattenbury MLA, Minister for Climate Change and Sustainability provided the keynote address.

Inaugural ANU Women in Energy meeting 19 June 2018

Held in conjunction with Open Day was the ECI's inaugural Women in Energy meeting. Drawing together women from across the campus whose research touches on energy, this meeting discussed gender related issues and how they impact upon the workplace. Our keynote speaker was Allison Hawke, Women in Renewables, Clean Energy Council. Panel members included Professor Margaret Jolly, The ANU Gender Institute; Associate Professor Carolyn Hendriks, Professor Ken Baldwin and Chair Professor Kylie Catchpole.

ECI seminars and public lectures

The status of ITER – the fusion reactor development project

Guest speaker Dr Barry Green, School of Physics of the University of Western Australia. Public lecture hosted by the Research School of Physics and Engineering, 6 December 2017.

Light management in photovoltaic materials

2017 Frew Fellowship Lecture delivered by Professor Albert Polman, leader of the 'Light Management in New Photovoltaic Materials' program at the NWO Institute AMOLF in Amsterdam, the Netherlands and Professor of Photonic Materials for Photovoltaics at the University of Amsterdam, 19 December 2017.

The sun rises for free: the science of solar energy generation

Theatrical demonstration on the beauty of light and how the sun can be used to generate the entire energy needs of our society at Questacon. Professor Albert Polman is a specialist in solar energy research and professor of Photonic Materials for Photovoltaics at the University of Amsterdam, the Netherlands. This public talk was supported by the Australian Academy of Science, Questacon and ECI, 24 January 2018.

Hydride material for energy storage and catalysis

Associate Professor Kondo-François Aguey-Zinsou, University of New South Wales, 14 March 2018.

A vision for powering our electricity grid with energy storage

Entrepreneurial Academic Scheme, Special Research Seminar by Dr Lachlan Blackhall, 15 March 2018.

Energy Conversations: The future of sustainable transport

Experts from the Australian National University and the ACT Government discussed the future of sustainable transport at the Renewables Innovation Hub. Hosted by the ECI and the Australian Institute of Energy, 20 March 2018.

Japan-Australia Energy Dialogue

Speakers from Japan and Australia converged at the Renewables Innovation Hub to discuss energy policy issues in Japan and Australia. This was a joint project of ANU, Waseda, Chuo, and Keio universities. Supported by a grant from the Toshiba International Foundation, 22-23 March 2018.

L to R: Dr James Prest & Hikaru Hiranuma at the Japan-Australia Energy Dialogue.

The National Energy Guarantee

Public lecture on Australia's proposed energy policy, the National Energy Guarantee, with speakers Clare Savage, Energy Security Board; Salim Mazouz, ANU and John Soderbaum, ACIL Allen Consulting, 10 April 2018.

Bruny Island smart battery trial

Launch event hosted by the ANU College of Engineering and Computer Science and the ANU Energy Change Institute, 12 April 2018.

Will the NEG transform Australia's energy landscape?

Second of two public lectures on the National Energy Guarantee. Speakers included: Shane Rattenbury, ACT Minister for Climate Change and Sustainability, alongside expert panel members Professor Frank Jotzo (ANU), Dr Hugh Saddler (energy consultant) and Katharine Murphy (Guardian Australia), 31 July 2018.

Energy Conversations: How renewables and storage will replace the coal clock

Public lecture by Dr Lachlan Blackhall and panel of experts held at the Renewable Innovations Hub. Hosted by the ECI and the Australian Institute of Energy, 11 September 2018.

Hydrogen for Australia's future

Dr Alan Finkel, Australia's Chief Scientist presented this public lecture convened by ATSE and held at University House. 10 October 2018.

Energy Conversations: Zero-carbon energy for the Asia-Pacific

ECI members and stakeholders will discuss the ECI's Grand Challenge and what it will mean for the ACT, Australia and the Asia Pacific. 3 December 2018.

Symposia

Social equity in the energy transformation

This Symposium examined how the energy transformation will affect social equity, and whether the transformation process can be harnessed to reduce, rather than exacerbate, social inequities in Australia. 23 October 2018.

L to R: Kirsty Gowans, ARENA; Carolyn Hendriks, ANU; Stephen Devlin, Evoenergy; Bruce Chapman, ANU; Franziska Mey, Community Power Agency & Renate Egan, UNSW.

EVENTS

OUTREACH

Roundtables

The 'Cooma Forum' – Snowy 2.0 renewable energy prospects

The Energy Change Institute hosted a roundtable discussion on how to grow Cooma as a centre of excellence for research, development, training and further education in renewable energy. The event, organised by Dr Mike Kelly (Federal Member for Eden-Monaro) included the Honorable Mark Butler, Shadow Minister for Climate Change and Energy, and Mr Pat Conroy, Shadow Assistant Minister for Climate Change and Energy, and was attended by key stakeholders in industry, government and academia. January 2018.

L to R: Prof Ken Baldwin, Mark Butler MP & Mike Kelly MP

ACT Climate Strategy to a Net Zero Emissions Territory

Academics from across ANU came together to consider the ACT Government's discussion paper on their draft climate strategy. Antonio Mozquiera, Director of Climate Policy with the ACT Government briefly introduced the roundtable and this was followed by discussion of the key elements. The roundtable preceeded a joint submission to the ACT Government's Climate Strategy by the Energy Change Institute and the Climate Change Institute. March 2018.

The Future of Nuclear Power in the US: front end and back end prospects

The future of nuclear energy appears cloudy in the United States: over the past six years, a number of nuclear power plants have shut down permanently, with others threatening shutdowns without help from state governments. This roundtable discussion was led by Dr Allison Macfarlane, the former President Obama's Chairman of the US Nuclear Regulatory Commission. She is now Professor of Science and Technology Policy at George Washington University, and Director of the Center for International Science and Technology Policy at the University's Elliott School of International Affairs. May 2018.

Dr Allison Macfarlane

Papua New Guinea study tour roundtable

A delegation from Papua New Guinea led by the Minister for National Planning, Richard Maru, came to ANU as part of their Independent Electricity Grids study tour. The delegation included civil servants from the Ministry of Planning, PNG Power, and others. There were Australian representatives from the Federal Government, the ACT Government, ITP Renewables and CWP Renewables and ECI members. July 2018.

Hydrogen for Australia's future: a synopsis of the COAG White Paper prepared by the Chief Scientist

Professor Ken Baldwin, Director, ECI and members of the Energy Change Institute met with Dr Alan Finkel, Australia's Chief Scientist to discuss the ECI's hydrogen economy research capabilities. October 2018. Part of ECI's mission is to disseminate information on energy change through outreach activities. The following list gives a sample of the types of activities ECI members have been involved in.

International engagement

The Energy Change Institute signed an MOU with the National Renewable Energy Laboratory, United States recognising the growth in shared energy research between the two organisations. This relationship will lead to new knowledge and greater sharing of results on clean energy. Signed by Professor Ken Baldwin, the MOU was formalised in Washington DC and witnessed by ACT Chief Minister Andrew Barr. 26 February 2018.

Dr James Prest, Professor Ken Baldwin and Associate Professor Llewelyn Hughes collaborated with energy law and policy researchers from three top Tokyo universities at a Japan – Australian Dialogue on Energy Policy & Regulation in Canberra. The workshop's theme centered on redesigning energy policy and regulation to promote innovation and achieve deep carbonization in Australia and Japan. 22 – 23 March 2018.

Professor Ken Baldwin, Dr Lachlan Blackhall, Dr Matthew Dornan and Dr Igor Skryabin met with a delegation of officials from Papua New Guinea, led by the Minister for National Planning, Richard Maru, as part of an Independent Electricity Grids study tour. The delegation included civil servants from the Ministry of Planning, PNG Power, and others. Following on from this meeting the ECI is establishing linkages with the PNG University of Technology's Sustainable Energy Research Institute. 18 July 2018

The Australia-Indonesia Centre's Energy Cluster concluded its four-year bilateral research program with workshops at the ANU and Monash University. Energy Cluster Co-Lead and Coordinator Dr Igor Skryabin was amongst 30 academics, students, government officials and industry representatives from Australia and Indonesia who came together to share research findings. 19 – 20 July 2018.

Associate Professor Penny King, Professor Wojciech Lipinski and Professor Adrian Sheppard were part of a team that hosted the Australia Academy of Science Elizabeth and Frederick White Conference "Frontiers in Gas-Solid Processes from the Atomic Scale to the Parsec". The conference had a strong focus on the capture and storage of CO_2 and attracted high-profile scientists worldwide. 5 – 7 September 2018.

Dr Igor Skryabin attended and chaired a session of the fourth Asia-Pacific Sustainable Energy Development Forum in Tianjin, China. The event was organized by the Asian-Pacific Sustainable Energy Centre (APSEC). Dr Skryabin is a Board Member of the APEC-funded APSEC. 20 – 22 September 2018. Professor Andrew Blakers assisted a group of graduates for a project entitled 'Small-scale hydropower in irrigation Graduate Industry Project' in the Commonwealth Department of Agriculture and Water Resources. December 2017.

Professor Ken Baldwin was Congress Chair of the OSA Light, Energy and the Environment Congress held on Sentosa Island, Singapore, 5 – 8 November 2018.

Members of the Solar Thermal Research Cluster served in the organising committees of major conferences and meetings including SolarPACES, the Asia-Pacific Solar Research Conference and the OSA Light, Energy and the Environment

Researchers from the Australia-Indonesia Centre met for a bilateral workshop at ANU in July 2018.

Congress. Cluster members also hosted numerous international senior delegations from India, China, Japan, Indonesia and Nigeria, and guest speakers from MIT, Imperial College, Sandia National Laboratories, Politecnico di Torino and Tohoku University.

Industry engagement

Dr Igor Skryabin is a Board member of the Australian Photovoltaic Institute, an Advisory Board member of the APEC Asia-Pacific Solar Energy Centre in China, a member of the NSW Energy and Resource Knowledge Hub, and a member of the organising committee of 2016 Asia-Pacific Solar Research Conference as well as leader of the "Energy in the Asia-Pacific" research stream of the conference.

Professor Quentin Grafton is a member of FE2W (Food Energy Environment Water), an international, non-profit association with 40 members from universities, multilateral organisations and nongovernment organisations committed to addressing the world's food, energy, environment and water challenges.

Community engagement

Dr Hemant Mulmudi took part in a science outreach program at Telopea Park School, Canberra, providing mentoring on a student-led project. July 2018.

MEDIA

The media is a key partner helping the ECI to engage and educate the wider community on topics relevant to energy change.

ECI members regularly provide expert commentaries on news relevant to energy technology and energy policy. Below are some examples:

National energy policy

"Renewable energy thriving, but needs more policy certainty", 10 September 2018, interview with Professor Ken Baldwin, AM, ABC Radio.

"Discussing the 'sorry saga' in Australia's environmental policy", 21 August 2018, interview with Professor Ken Baldwin, CNBC.

"What next now the NEG has collapsed in a festering heap?" 21 August 2018, written by Professor Frank Jotzo. The Sydney Morning Herald.

"The renewable energy train is unstoppable. The NEG needs to get on board", 15 August 2018, written by Prof Ken Baldwin, The Conversation.

"What is the NEG?" 14 August 2018, interview with Professor Ken Baldwin, Radio National Drive,

"NEG will 'fail to lift' investor confidence', Dr James Prest, 13 August 2018, Canberra Times.

"Will the National Energy Guarantee stall or speed up progress?" Podcast with Professor Ken Baldwin, 10 August 2018, The Guardian.

"Could the NEG bring down power prices? It's hard to be confident that it will", 4 August 2018, written by Salim Mazouz, Professor Frank Jotzo, Honorary Associate Professor Hugh Saddler, The Conversation.

"The energy guarantee ruckus shows why we need independent policy analysis", 2 August 2018, written by Professor Frank Jotzo, The Guardian.

"Up in smoke: what did taxpayers get for the \$2bn emissions fund?" interview with Dr Paul Burke, 3 June 2018, The Guardian.

"Federal energy plan may curb state ambitions", interview with Professor Frank Jotzo, 16 April 2018, Canberra Times.

"We must fix the foundation of our energy policy to get out of the current mess", 11 April 2018, written by Frank Jotzo (ANU), Salim Mazouz (ANU and Natural Capital Economics), Dylan McConnell (University of Melbourne) and Hugh Saddler (ANU and private consultant). The Guardian.

"Climate wars have cost us the chance to lead", written by Honorary Professor John Hewson, 14 March 2018, Canberra Times.

Decarbonisation of energy

"'Overwhelming' economics favour accelerating shift from coal, report says", Interview with Professor Frank Jotzo, 5 September 2018, Sydney Morning Herald.

"At its current rate, Australia is on track for 50% renewable electricity in 2025'", 10 September 2018, written by Professor Ken Baldwin, Professor Andrew Blakers and Dr Matt Stocks. The Conversation.

"New coal doesn't stack up – just look at Queensland's renewable energy numbers", 2 July 2018, written by Dr Matthew Stocks and Professor Andrew Blakers, The Conversation.

"Solar PV and wind are on track to replace all coal, oil and gas within two decades", written by Professor Andrew Blakers and Dr Matthew Stocks, 6 April 2018, The Conversation.

"The Nationals should support carbon farming, not coal", written by Professor Andrew Hopkins, 6 April 2018, The Conversation.

Transport and energy

"Road deaths linked to low petrol prices, ANU research finds", interview with Dr Paul Burke, 26 August 2018, Canberra Times.

"How EVs will fast-track Australia's shift to 100% renewables", interview with Professor Andrew Blakers, 25 May 2018, Renew Economy.

"Fact check: Does Australia have three weeks of petrol in reserve?", interview with Associate Professor Llewelyn Hughes, 24 May 2018, ABC News online.

"Is Australia running out of fuel? PM orders supply review", interview with Dr James Prest, 7 May 2018, BBC online.

"Fuel excise a good option for Indonesia", interview with Dr Paul Burke, 14 October 2017, Jakarta Post.

Energy storage

"Indonesia has far more than enough pumped hydro storage sites to support a 100% renewable electricity gird", written by Professor Andrew Blakers, Bin Lu and Dr Matthew Stocks, 3 May 2018. The Conversation

"Bruny Island trial a microcosm for future energy system", interview with Dr Lachlan Blackhall, 23 April 2018, Sydney Morning Herald.

"Tesla's 'virtual power plant' might be second-best to real people power, written by Hedda Ransan-Cooper et al, 20 February 2018, The Conversation.

Media releases

The ANU publicises ECI research and news via media releases. Coverage generated by an ANU media release can have broad reach. For example in September 2017, the ANU press release - 'Hydro storage can secure 100% renewable electricity' - reached an audience of more than 4.5 million people.

Delivering zero-carbon energy to the Asia-Pacific: 2018 Grand Challenge winner 21 September 2018

Energy policy needs to get on board the renewable energy train 10 September 2018

ANU awarded more than \$3.4m in renewable hydrogen research 7 September 2018

ANU researchers awarded top science prize 30 August 2018

NEG could place Australia at the back of the pack 11 August 2018

ANU experts comment of National Energy Guarantee 10 August 2018

ANU helping build cheaper and greener electricity networks 12 April 2018

ANU announces new leader of battery storage program 6 April 2018

China's emissions trading scheme in the spotlight 4 April 2018

ANU to strengthen research collaboration with US National Renewable Energy Laboratory

26 February 2018 Our main communication channels have been events, media relations and digital communications, including ANU-invented solar technology helps University reduce emissions ANU websites, a regular e-marketing program to our database 7 February 2018 of 5,000 subscribers and social media (including Twitter: @ ANUEnergyChange, and Facebook: ANU Energy Change).

Graham Farguhar named 2018 Senior Australian of the Year 29 January 2018

Australia can meet carbon emission target at zero net cost 27 November 2017

Media releases

Media generated by the Energy Change Institute Executive for the 6 months to 3 October 2018 reached an audience of more than 10 million people (isentia Media Monitoring).

Communications

ECI Communications in 2018 have been focused on promotion of ECI research and events, building and supporting ECI membership, strengthening partnerships and connections between ECI members and external stakeholders in government, industry, NGOs and the community and promoting the Master of Energy Change degree.

HONOURS AND AWARDS

Professor Xuemei Bai - 2018 Volvo Environment Prize

Professor Xuemei Bai was awarded the 2018 Volvo Environment Prize for her pioneering work on urbanisation, and urban system sustainability in Asia and globally. The Volvo Environmental Prize is one of the most prestigious global awards recognising outstanding scientific discoveries in environment or sustainability fields. Professor Bai is a member of the ECI Energy Efficiency research cluster.

Dr Cormac Corr - Senior Fellowship of the Higher Education Academy

This prestigious and internationally recognised professional award is given in recognition of long experience and noted expertise in tertiary education. Dr Corr is a member of the ECI Fusion Power research cluster.

Dr Christian Downie - DECRA & AllA Research Impact Award

Dr Christian Downie has received a Discovery Early Career Researcher Award (DECRA) from the Australian Research Council as well as an Early Career Research Impact Award from the Australian Institute of International Affairs for 2018. Dr Downie's DECRA was awarded for his research project proposal "Who governs global energy? The role of informal international organisations" which aims to improve how energy is governed at the global level. Dr Downie is a member of three ECI research clusters: Energy and Security, Energy Economics & Policy and Energy Regulation & Governance.

Professor Graham Farguhar AO - 2018 Senior Australian of the Year

Distinguished scientist and ANU Professor Graham Farguhar AO won the 2018 Senior Australian of the Year award. This award caps a series of accolades for Professor Farguhar in recent years. He was recognised for his work in plant biophysics and photosynthesis, which has involved research on water-efficient crops and the impacts of climate change. Professor Farguhar is a member of the ECI Renewable Fuels research cluster.

Professor Chennupati Jagadish - elected to the Indian National Academy of Engineering

Distinguished Professor Chennupati Jagadish is the recipient of four awards/honours: 1) election to the Indian National Academy of Engineering. 2) 2018 Recognition Award from the Nanometer Science and Technology Division of the American Vacuum Society. 3) The Nayudamma Centre for Development Alternatives in India. This accolade is given to distinguished Indians and celebrates their impact in fields of science and technology. 4) UNESCO Medal for contribution to development of nanoscience and nanotechnologies. Professor Jagadish is a member of the ECI Solar Photovoltaics research cluster.

Professor Mark Humphrey - 2017 RACI Leighton Memorial Award

Professor Mark Humphrey has received the Royal Australian Chemical Institute (RACI) Leighton Memorial Award. This award recognises eminent services to chemistry in Australia in the broadest sense, including research, technology, public service, and national leadership; it is the RACI's most prestigious award. Professor Humphrey is a member of the ECI Artificial Photosynthesis research cluster.

Dr Zongyou Yin – Web of Science 2017 Highly Cited Researchers

Dr Zongyou Yin was named one of the Web of Science 2017 Highly Cited Researchers. Web of Science is a popular online subscription-based citation indexing service. Dr Yin is a member of three ECI research clusters: Carbon Capture and Storage; Energy Storage & Recovery and Renewable Fuels.

Eureka Prize for Environmental Research

Professor Andrew Blakers, Dr Matthew Stocks and Bin Lu were awarded the NSW Office of Environment and Heritage Eureka Prize for Environmental Research, for their work challenging the barriers to renewable energy in Australia. Their research shows Australia can transition smoothly to 100% renewable electricity while retaining eliability of supply. The team discovered 22,000 sites that are potentially suitable for cost-effective pumpedhydro energy storage, which can be used to help build a secure and cheap Australian electricity grid with 100

eft to Right: Eureka Prize winners Bin Lu, Andrew Blakers & Matthew Stocks Photo credit: Lannon Harley

HONOURS AND AWARDS

OUTLOOK

Bruny Island smart battery trial scoops three awards

The CONSORT Bruny Island Battery Trial, a trial of household solar and battery storage off the coast of Tasmania picked up three awards in 2018.

- The Electric Energy Society of Australia (EESA)'s Energy Project of the Year,
- The Clean Energy Council's Community Engagement Award,
- Engineers Australia's Tasmanian Engineering Excellence Award, putting CONSORT in the running for the National Engineering Excellence Award.

The trial uses a world-leading software platform developed at ANU. ECI members who contributed to the CONSORT project were: Professor Sylvie Thiébaux, Dr Paul Scott, Dr Dan Gordon, Dr Evan Franklin and Dr Lachlan Blackhall. CONSORT is a collaboration between three universities (The Australian National University, The University of Sydney, and The University of Tasmania), electricity network provider TasNetworks, and Canberra-based startup Reposit Power.

Members of the CONSORT team receiving Engineers Australia's Tasmanian Engineering Excellence Award in Hobart in August 2018.The ECI's Dr Evan Franklin and Professor Sylvie Thiebaux are second and third from the left respectively.

2017 ANU Media and Outreach Awards:

L to R: Ken Baldwin, Andrew Blakers, Frank Jotzo and Christian Downie.

Four ECI members were recognised for their contributions to public discourse at the ANU Media and Outreach Awards announced in December 2017. Professor Ken Baldwin, Professor Andrew Blakers, Professor Frank Jotzo and Dr Christian Downie were joint winners of Improving the Quality of Public Debate Award.

Professor Andrew Blakers received a second honour - Impact Award for Reach and Influence.

Photo credit: James Prest.

With the opportunities arising from our numerous funding successes, including the Grand Challenge Zero-Carbon Energy for the Asia-Pacific, the outlook for the ECI is bright.

Early in the new year we will appoint a Chief Operating Officer for the Grand Challenge and assemble a team of bright, young multidisciplinary researchers to move the Grand Challenge forward. We will work with our existing collaborators in industry, government and the wider community to leverage the University investment further, and in particular will engage with the Department of the Environment and Energy and the Department of Foreign Affairs and Trade to increase the reach and impact of this enterprise.

Our research portfolio is expanding, as exemplified by our growing expertise in the hydrogen economy, smart grids and indigenous engagement, and we will search for new niches and funding opportunities to bolster these research areas.

And, with the Federal election on the horizon, we can but hope that in the coming year we will at long last see the alignment of energy and climate policy at a national level – ideally in a bipartisan agreement. The ECI will start local – with the ANU Energy Master Plan for creating a low-carbon, affordable campus – and will move global through our research linkages worldwide. We will continue our strong engagement with industry, and will partner with government (both state and national) to provide the research understanding needed for Australia's energy transition.

Please visit our website (energy.anu.edu.au), follow us on Twitter (@ANUEnergyChange) and Facebook (ANU Energy Change), and subscribe to our mailing list (via our website) for the latest developments.

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EXECUTIVE MEMBERSHIP

Professor Armin Aberle – CEO, Solar Energy Research Institute of Singapore

Armin Aberle serves as CEO of the Solar Energy Research Institute of Singapore (SERIS) at the National University of Singapore (NUS). His research focus is on photovoltaic materials, devices and modules. In the 1990s he established and led the Silicon Photovoltaics Department at the Institute for Solar Energy Research (ISFH) in Hamelin, Germany. He then worked for 10 years in Sydney, Australia as a professor for photovoltaics at the University of New South Wales. In 2008 he joined NUS to establish SERIS, as the Deputy CEO and the Director of the Silicon PV Department. Since 2012 he serves as SERIS CEO. He is presently the Director of the Institute's Silicon Materials & Cells Cluster and the Novel PV Concepts Cluster.

Mr Brad Archer - First Assistant Secretary, Department of the Environment and Energy

Brad Archer is the head of the International Climate Change and Energy Innovation Division in the Australian Government Department of the Environment and Energy. Brad's responsibilities include: providing advice on clean energy innovation; overseeing the Government's inventory of Australia's greenhouse gas emissions and supporting Australia's participation in international climate change negotiations. Brad is an economist by training and has been working on climate change policies since March 2011. Prior to this Brad worked on a range of issues in the Australian Treasury, which he joined in 1991.

Mr Stephen Devlin - General Manager, Evoenergy

Stephen Devlin is responsible for Evoenergy's energy networks asset strategy and planning functions. He is also responsible for the gas networks business, technical regulatory standards, major customer connections and smart networks developments. He has a breadth of experience in the energy, water and waste sectors, having worked across many facets of the electricity, water, gas and waste industries for 30 years. Stephen holds a Bachelor of Engineering (Electrical), a Master of Business Administration, Master of Commercial Law and a Juris Doctor.

Dr Bruce Godfrey - Principal, Wyld Group Pty Ltd

Bruce Godfrey's career has been built in business, innovation investment and technology development fields. He has focused on the advancement and commercialisation of technologies (particularly new energy technologies - renewable, enabling and low emission fossil), investment readiness of products and companies, and innovation policy and programs. A Fellow of the Academy of Technology and Engineering (ATSE), he is a Director and Vice-President Diversity of the Academy as well as Chair of ATSE's Energy Forum. He has chaired Expert Working Groups for the Australian Council of Learned Academies (ACOLA) on Delivering Sustainable Urban Mobility (2015) and on Energy Storage (2017).

Professor Mark Howden – Director, ANU Climate Change Institute

Mark Howden is the Director of the Climate Change Institute at the Australian National University. He is also an Honorary Professor at Melbourne University's School of Land and Food. Mark's work has focused on how climate impacts on, and innovative adaptation options for, systems we value: agriculture and food security, the natural resource base, ecosystems and biodiversity, energy, water and urban systems. He has been a major contributor to the Intergovernmental Panel on Climate Change (IPCC) Second, Third, Fourth and Fifth Assessment reports and various IPCC Special Reports, sharing the 2007 Nobel Peace Prize with other IPCC participants and Al Gore. Recently Mark sat on the US Federal Advisory Committee for the 3rd National Climate Assessment and he participates in several other international science and policy advisory bodies.

Dr Sarah Pearson - Chief Innovation Officer, Department of Foreign Affairs and Trade

Sarah Pearson is an internationally experienced Open Innovation practitioner, innovation ecosystem builder, scientist and advocate for collaborative innovation and entrepreneurship in Australia. In her current role Sarah is responsible for leading, developing and scaling innovation practice and culture across DFAT and through whole of government activity. Sarah is also a member of Questacon's Advisory Council, and member of the Investment Committee for CSIRO's \$200M VC fund, Main Sequence Ventures. She is an inventor on eight international patent applications for cancer diagnosis and novel confectionary. Sarah was awarded a PhD from the University of Oxford in particle physics, and has published research in the areas of particle physics, medical physics, artificial intelligence, innovation, science communication and science policy.

Professor Ken Baldwin - ANU College of Science

Ken Baldwin is the Founding Director of the Energy Change Institute at ANU, and Deputy Director of the Research School of Physics and Engineering. From 2011-13 he was a member of the Project Steering Committee for the Australian Energy Technology Assessment, and in 2015/16 was a member of the Socioeconomic Modelling Advisory Committee to the South Australian Royal Commission into the Nuclear Fuel Cycle. Ken is an ANU Public Policy Fellow, and is a Fellow of the American Physical Society, the Institute of Physics (UK), the Optical Society of America and the Australian Institute of Physics.

Professor Andrew Blakers - ANU College of Engineering and Computer Science

Andrew Blakers is Professor of Engineering at ANU. He was a Humboldt Fellow and has held Australian Research Council QEII and Senior Research Fellowships. He is a Fellow of the Academy of Technological Sciences & Engineering, the Institute of Energy and the Institute of Physics. He is a Public Policy Fellow at ANU. He has published approximately 300 papers and patents with research interests are in the areas of silicon photovoltaic solar cells and solar energy systems. He was a leader of the team that developed PERC silicon solar cell technology, which currently has approximately 30% of the worldwide solar market and cumulative module sales of around \$30 billion (mid-2018). He also has interest in sustainable energy policy and is engaged in detailed analysis of energy systems with high (50-100%) penetration by wind and photovoltaics with support from pumped hydro energy storage (for which he won the 2018 Eureka Prize for Environmental Research).

Professor Kylie Catchpole - ANU College of Engineering and Computer Science

Professor Kylie Catchpole, Research School of Engineering, has research interests in new materials for solar cells and solar fuels as well as the broader energy transition. She has a physics degree from the ANU, winning a University Medal, and a PhD from the ANU. She was a Post-doctoral Fellow at the University of New South Wales and the FOM Institute for Atomic and Molecular Physics, Amsterdam. She has published over 100 papers, which have been cited over 8000 times to date. Her work on nanophotonic light trapping was listed as one of MIT Technology Review's '10 most important emerging technologies'. In 2013 she was awarded a Future Fellowship from the Australian Research Council and in 2015 she was awarded the John Booker Medal for Engineering Science from the Australian Academy of Science.

Llewelyn Hughes is Associate Dean, Research for the College of Asia and the Pacific, and Associate Professor in the Crawford School of Public Policy. His academic work focuses on the regulation of natural resource markets, and the political economy of climate change. Llewelyn joined the ANU in 2014 from the Elliott School of International Affairs at George Washington University. He received his PhD from the Massachusetts Institute of Technology, and holds a Master's degree from the Graduate School of Law and Politics at the University of Tokyo.

Professor Yun Liu – ANU College of Science

Yun Liu graduated from the Xian Jiaotong University, China with her BSc, MSc and PhD. She has since held a position at the National Institute of Advanced Industrial Science and Technology (AIST), Kyushu, Japan (1998-2001) before the commencement of her Postdoctoral Fellow position at the Research School of Chemistry, ANU in 2001. She was awarded fellowships of the AIST (1998-1999), the Science and Technology Agency (1999-2001, now renamed as the Fellow of Japan Society for the Promotion of Science) and the Australian Research Council (ARC) Queen Elizabeth II (2006-2010). She was made a fellow of the Australian Institute of Physics (FAIP) and Certified Materials professional (CMP). She was also a member of the Materials of Australia (MMA) and the Society of Crystallographers in Australia and New Zealand (MSCANZ).

Dr James Prest - ANU College of Law

James Prest lectures in law at the ANU specialising in environmental law. He is a Member of the IUCN Commission on Environmental Law and works on renewable energy law and major projects legislation. After graduating from ANU and gaining admission to practise in the Supreme Court of the ACT in 1995 he worked many years as a legal policy officer at the Department of Prime Minister and Cabinet. He also held positions as a Research Officer at the Law and Bills Digest Group of the Parliamentary Library in Canberra and as an adviser at Parliament House.

Dr Igor Skryabin, Research & Business Development Manager - ANU College of Science

Igor Skryabin's career has spanned both industry and academia. His major technical contribution has been in the development and commercialisation of solar technologies. Igor has published more than 100 research papers and is an inventor of more than 30 patents and industrial designs, granted in Australia and overseas. Igor is a co-lead/coordinator of the Australia-Indonesia Energy Cluster, Board Member of the Australian Photovoltaic Institute and of the Asia-Pacific Sustainable Energy Centre in China.

Professor Sylvie Thiebaux – ANU College of Science

Sylvie Thiebaux's research interests are artificial intelligence and its optimisation and applications to smart grids. She leads the CONSORT project in developing and trialling methods enabling consumer-owned battery systems to provide owner value while supporting the grid, with ANU, University of Sydney, University of Tasmania, TasNetworks, Reposit Power, and ARENA. She is an associate editor of the Artificial Intelligence journal, an AAAI Councillor, former President of the board of directors of International Conference on ICAPS, and a former Director of the Canberra Laboratory of NICTA.

Associate Professor Llewelyn Hughes - ANU College of Asia and the Pacific

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Dr Grace Chiu	Co
Professor Denis Evans	Co
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Professor Weifa Liang	Со
Dr Adrian Lowe	Со
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