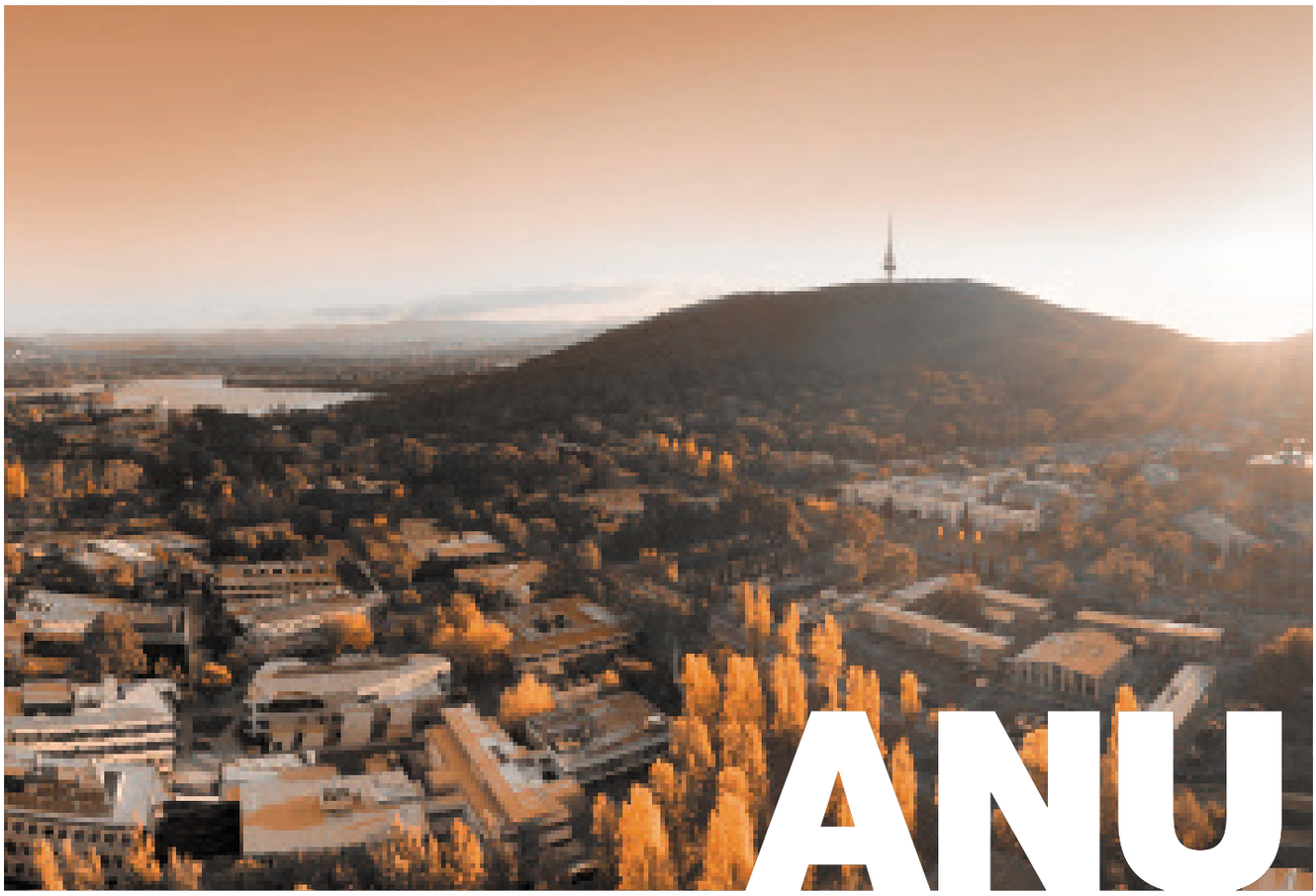
Australian National University



ANU ENERGY CHANGE INSTITUTE

ANNUAL REPORT

2020

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Front cover image: ANU campus

MESSAGE FROM THE DIRECTOR

2020 marks ten years since the foundation of the ANU Energy Change Institute - which was announced at the Solar 2010 conference held at ANU in December that year.

During this time, the ECI has developed a national and international profile for the University in energy research, education, public policy and broader outreach, that has made it a 'go to' organization for energy expertise, commentary and advice. It is because of the ECI's profile that the ANU is trusted and respected by policy makers, industry, the media and the general public because of its high-level multi-disciplinary expertise, and its technology and policy neutral approach which allows all research to grow without favour under its umbrella.

This progress has extended in 2020 despite the pandemic, and the ECI research, education and outreach programs continue to develop.

The ten-year growth of the ECI is mapped out in the timeline following this foreword. Starting with 14 research topics, we have expanded now to 20 research clusters, and membership has more than doubled from around 90 to nearly 200 researchers, in addition to their PhD students.

During this time the ECI has been responsible for developing entirely new areas of research at ANU, such as the Battery Storage and Grid Integration Program, and research on the Hydrogen Economy. It has attracted tens of millions of dollars in new research funding which would not otherwise have been brought to the University.

Through our outreach and engagement programs ECI has connected with thousands of key stakeholders and members of the wider community to the work being undertaken at ANU. This includes partnerships with industry and the public service, as well as the provision of trusted advice to both state and federal governments through parliamentary submissions and direct engagement.

The ECI education programs have also disseminated knowledge on Energy Change to employees in government, industry and the wider community – both in Australia and internationally. Through the dozens of graduates from the Master of Energy Change and the hundreds of participants in our professional short courses there is now a wider understanding of – and capability to help implement – the energy transition.

The ECI has played a similar leadership role in the formation of the Energy Research Institutes Council for Australia (ERICA), a consortium of 12 university energy institutes comprising most of the energy research capacity in Australian universities. As founder and inaugural Chair of ERICA, in 2019 I chaired the first State-of-Energy-Research Conference at ANU under ERICA's auspices. Subsequently, I was asked to join the Steering Committee of the ACOLA Australian Energy Transition Research Plan which is being led by the Chair of the Australian Energy Market Operator Board, Drew Clarke AO.

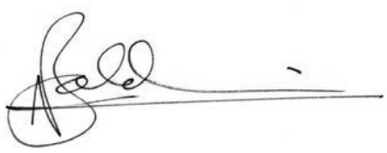
Finally, in breaking news, from 2021 the ANU Energy Change Institute will merge with the Climate Change Institute and the Disaster Risk Science Institute to form a new Institute – the Institute for Climate, Energy & Disaster Solutions (ICEDS). The aim is to provide an overarching organisation that will link the individual pillars and add value to their work across a broader portfolio of activity.

Be assured that Energy at ANU will continue to have the same capability and profile that it has in the past – augmented by the partnership with its sister organisations. I will continue to play a role in ensuring the ANU Energy program continues its contribution to the wider Australian sector, as we transition to a new Head of Energy over time.

I will also continue in 2021 as Director of the Grand Challenge: *Zero-Carbon Energy for the Asia-Pacific* as it continues its research with industry and government to underpin the development of new export opportunities with the region, based on renewable energy.

I look forward to having you participate in our activities under the new Institute umbrella, and hope to welcome you back on campus at one of our events as we advance after the pandemic.

Yours sincerely



Professor Ken Baldwin

2010-2020 - 10 YEARS OF THE ECI

2010

The Energy Change Institute is established at the Solar Conference hosted by the ANU in December.

2011

March - Prime Minister Julia Gillard visits the ANU Big Dish and the solar laboratories

April - Energy Minister Martin Ferguson launches a photovolatic project in which ANU will collaborate with Trina solar, one of the world's largest manufacturers of solar cells.

July - first ECI Professional Short Course on energy offered to Commonwealth public servants.

September - ECI launches the ANU Master of Energy Change.

Prime Minister Julia Gillard visits the ANU Big Dish solar thermal facilities, accompanied by Dr Keith Lovegrove. Photo by Lisette Hähnel.

2012

First semester - seven students begin the first intake of the ANU Master of Energy Change

April - ANU unveils inaugural Public Policy Fellows, one-third of whom are ECI members: Prof Ken Baldwin, Prof Andrew Blakers and Prof Warwick McKibbin.

October - ECI hosts major national forum, 'Australia's Energy Future', the precursor to 'Energy Update'.

Prof Joachim Luther, former director, Fraunhofer Institute for Solar Energy Systems, Germany, gives ANU/ACT Government Solar Oration.

2013

Daniel Harding becomes first graduate of ANU Master of Energy Change

May - ECI hosts roundtable meeting for visit to Australia by Professor Cayetano Lopez, Director of Spain's renewable energy research agency CIEMAT. ECI and CIEMAT sign a Memorandum of Understanding to foster research collaboration.

July - ECI responds to Vice-Chancellor's call to reduce energy costs. Institute works with Facilities & Services Division to lower energy costs by 10% per annum, including through efficiencies.

August - ECI meets representatives from Department of Defence to understand Defence's energy needs & provide expertise.

October - Giles Parkinson, founder of *Renew Economy* news, gives ANU/ACT Government Solar Oration.

2014

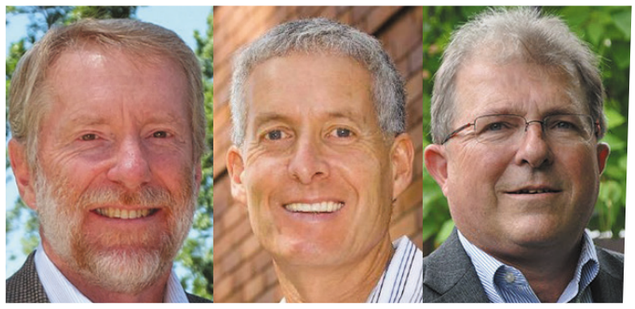
March - ECI is part of the Defence Department's Land Power and Energy Roadmap. ECI is the sole tertiary research institution (along with Defence Science and Technology Organisation) to be invited to participate in Defence Energy Symposium.

March - Science Meets Parliament. ECI is among ANU institutes and colleages to sponsor the 2014 event.

May - Three new ECI members appointed ANU Public Policy Fellows: Assoc Prof Karen Hussey, Assoc Prof Frank Jotzo, and ECI Advisory Board member Prof Mike Raupach.

June - ECI joins the Australia-Indonesia Centre, alongside three other universities. ECI's Dr Igor Skryabin addresses the AIC inaugural summit in Jakarta.

June - US President Barack Obama announces deeper collaboration between the US and Australia in clean energy technology research, which includes an ECI-led initiative to forge stronger links between the ANU and the United States National Renewable Energy Laboratory (NREL).



ANU inaugural Public Policy Fellows Prof Ken Baldwin (left), Prof Andrew Blakers, and Prof Warwick McKibbin.

July - Opening of $7.6m Fusion Facility Upgrade and launch of the Australian Plasma Fusion Research Facility at the ANU.

August - ANU receives $9m in energy research funding from the Australian Renewable Energy Agency (ARENA).

September - ANU Energy Green Paper Forum convenes with panel of expderts from industry, government and academia ahead of the Australian Government's Energy Green Paper.

November - ARENA chair Greg Bourne gives the ANU /ACT Government Solar Oration 2014.

December - ANU hosts the OSA Optics and Photonics Congress: Light Energy and the Environment. Speakers incude Nobel Laureate and former US Energy Secretary, Prof Stephen Chu of Stanford University, who also addresses the ANU Energy Update 2014.

2015

Feb - As part of its successful bid for the ACT Government's wind energy auction, Windlab agrees to partner with the ECI to deliver a new Masters and undergraduate course in Wind Energy.

2010-2020 - 10 YEARS OF THE ECI

April - More than 130 people attend a public forum hosted by the ANU on the Australian Government's Energy White Paper and heard from experts from academia, government and the private sector.

August - Roundtable with the Intergovernmental Panel on Climate Change (IPCC) featuring several ECI members.

September - ECI hosts and facilitates first Australia-Indonesia Centre Energy Cluster Workshop featuring Australian and Indonesian energy researchers.

December - Dr Pierre Verlinden, Chief Scientist, Trina Solar, gives the ANU/ACT Government Solar Oration.

2016

February - ECI hosts panel of experts from Australia and Switzerland on creating energy efficient cities.

Nobel Laureate and former US Energy Secretary, Prof Stephen Chu of Stanford University addresses the ANU Energy Update 2014.

May - ECI introduces the Energy Conversations series, co-hosted with the Australian Institute of Energy (ACT Branch), and features an expert panel on integrating renewables into the grid.

September - The ANU and ACT Government announce the creation of a new Battery Storage and Integration Research Program as part of a $8m partnership.

October - ECI and Engineers Australia present a forum on Energy Security on Australia's resilient energy future, and energy and global risks.

November - Then Australian Energy Minister, Josh Frydenberg MP, addresses the ANU Energy Update 2016. Jeremy Leggett, author & chairman of SolarAid, gives he ANU/ACT Government Solar Oration

2017

June - ECI holds a public forum to explain Chief Scientist Dr Alan Finkel's review into the National Electricity Market.

July - ECI hosts Dr Martin Keller, Director of the United States National Renewable Energy Laboratory, for a lecture on the US energy transition.

August - the ECI is instrumental in the launch of the Energy Research Institutes Council for Australia (ERICA) to provide governments with research-led advice. The initial membership comprises seven universities.

September - ECI signs MOU with ITRI, the Taiwanese Industrial Technology Institute.

November - Audrey Zibelman, CEO of the Australian Energy Market Operator (AEMO) delivers the ACT Government/ANU Solar Oration on the Australian Energy Transition.

2018

February - The ECI signs an MOU with the US National Renewable Energy Laboratory to collaborate on energy research.

Ms Audrey Zibelman, CEO of the Australian Energy Market Operator (AEMO) delivers the Solar Oration 2017.

April - ANU names Dr Lachlan Blackhall as leader of the $8m Battery Storage & Grid Integration Program.

June - ECI established the Women in Energy Network to support ANU researchers working in energy. Its first chair is Prof Kylie Catchpole.

November - Ivor Frischknecht, inaugral CEO of the Australian Renewable Energy Agency, delivers the ANU/ACT Government Solar Oration.

2019

July - ECI hosts Australia's first State-of-Energy-Research conference, organised by the Energy Research Institutes Council for Australia (ERICA).

November - ECI, in collaboration with ERICA, the International Energy Agency and Australia's Energy Security Board hosts the invitation-only Future Electricity Markets Summit in Sydney.

ECI signs MOU with ENEA, the Italian Energy Agency.

December - Fleur Yaxley, renewable energy industry senior executive, delivers the ANU/ACT Government Solar Oration.

2020

February - ECI and Global Power Generation Australia announce a 20-year $1.5m Hydrogen Economy Research Fund.

October - Public webinar featuring Chief Scientist Alan Finkel and the Low Emissions Technology Roadmap.

November - Prof Mark Z Jacobson (Stanford University) delivers the ANU/ACT Government Solar Oration.

December - First Australia-Italy Hydrogen Workshop following 2019 MOU with ENEA.

2020 HIGHLIGHTS

From ECI Open Day 17 February 2020 to ANU Energy Update 3 December 2020.

ECI Open Day
17 February 2020

The ECI Open Day provides a platform for exchanging ideas for ANU based researchers and stakeholders working in the field of energy change. 2020 highlights included presentations on a research plan for Australia's energy transition by Drew Clarke AO PSM, Board Chairman of the Australian Energy Market Operator (AEMO), Darren Miller, CEO of the Australian Renewable Energy Agency, and a hydrogen research project collaboration agreement between the ECI and Global Power Generation Australia.

Darren Miller, CEO of ARENA (far left), addressed at full house at the 2020 ANU Energy Open Day.

20-year, $1.5m Hydrogen Economy Research Fund
February 2020

Global Power Generation Australia (GPGA) unveiled funding worth $75,000 a year for the ANU Energy Change Institute to conduct research on the hydrogen economy over the next two decades. The funds comprise a $25,000 research scholarship for a Master's student, and $50,000 to support research and education on the hydrogen economy.

From left, David Santo Tomas (GPGA), ECI Director, Prof Ken Baldwin, and Shane Rattenbury MLA, ACT Minister for Climate Change and Sustainability.

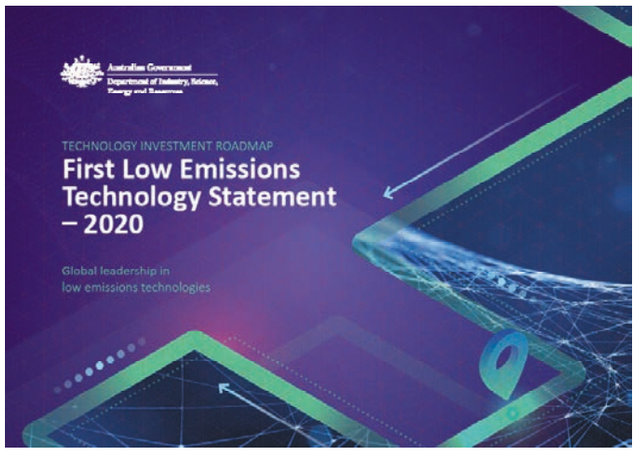
ANU-ActewAGL project to better understand electricity use in poorly-insulated housing
May 2020

Dr Lee White's research project to explore home insulation and electricity use was named the 2020 winner of the Icon Water and ActewAGL Perpetual Endowment Fund. Dr White will collaborate with the electricty utility for 12 months to determine the impact of housing energy efficiency on bill charges, driven by time-of-use rates. The project aims to support the development of modernised electricity billing systems in a way that improves, rather than exacerbates, existing inequities.

Dr Alan Finkel AO and Australia's Technology Investment Roadmap
June and October 2020

The ECI hosted two public forums in 2020 which explored the Australian Government's Technology Investment Roadmap. The first, in June, was held in conjunction with the ANU Climate Change Institute, comprised specialists from industry, the CSIRO, the ANU, and senior officials from the Department of Industry, Science, Energy and Resources (DISER) who helped develop the roadmap discussion paper.

The second webinar, in October, featured Australia's former Chief Scientist, Dr Alan Finkel AO, who chaired an expert group which developed the Roadmap and Low Emissions Technology Statement. His detailed presentation was followed by a panel comprising specialists from ANU, CSIRO and ClimateWorks Australia.



The ECI hosted two public forums on the Australian Government's Technology Investment Roadmap. Dr Alan Finkel, Australia's former Chief Scientist, was the guest speaker at the October forum.

2020 HIGHLIGHTS

Realising Electric Vehicles-to-grid Services (REVS) trial begins with government & industry fleets July 2020

Researchers in the Battery Storage and Grid Integration Program began an Australian-first, two-year trial to learn how electric vehicles can support Australia's grid. Supported by $2.4m from ARENA, the project involves 50 ACT Government Nissan LEAF EVs and one ActewAGL Nissan Leaf to study how the cars can supply power to the grid almost instantly when needed, to avoid blackouts. The ANU team will also unlock the wider potential of vehicle-to-grid (V2G) services by researching their social, technical and economic aspects. The REVS project consortium coverse the whole electricity and transport supply chains including ActewAGL, Evoenergy, Nissan, SG Fleet, JET Charge, ACT Government and the ANU.

The two-year Realising Electric Vehicles-to-grid Services (REVS) project aims to demonstrate the reliability and viability of vehicle-to-grid services at scale. Photo courtesy Nissan Australia.

Community-led energy projects September 2020

Dr Marnie Shaw, a Research Leader in the Battery Storage and Grid Integration Program, served on an expert panel which advised federal Member for Indi, Dr Helen Haines MP, for Dr Haines' Local Power Plan community energy project. Launched in September, the project aims to transform the way regional Australia generates and distributes electricity using renewable energy.

Dr Marnie Shaw, a Researcher Leader in the Battery Storage and Grid Integration Program.

Three ECI researchers at Smart Energy Conference September 2020

Dr Emma Aisbett, Dr Lachlan Blackhall, and Professor John Hewson were panelists at the Smart Energy Council's 'Smart Energy Conference and Exhibition'.

Dr Aisbett spoke about the ANU Grand Challenge: *Zero-Carbon Energy for the Asia-Pacific*, of which she is Associate Director (Research).

Dr Blackhall, Head of the Battery Storage and Grid Integration Program, discussed opportunities for Community & Suburb Scale Battery Storage.

Professor Hewson spoke about the consequences of inaction on reducing Australia's emissions and combatting climate change.

Dr Emma Aisbett addressed the Smart Energy Council's annual conference and discussed the ANU Grand Challenge: *Zero-Carbon Energy for the Asia-Pacific.*

2020 HIGHLIGHTS

ANU / ACT Government Solar Oration 17 November 2020

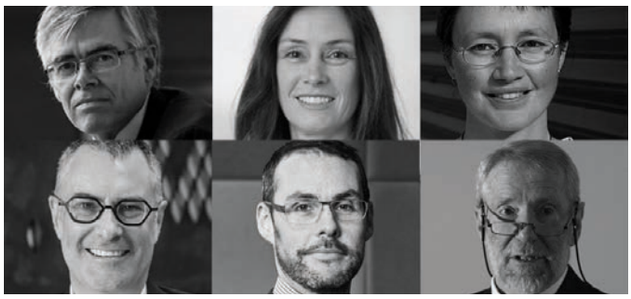
The Solar Oration was delivered by Professor Mark Z Jacobson, Director of the Atmosphere Energy Program at Stanford University. He discussed transitioning the world to 100% clean, renewable energy, and how the result of the 2020 US Presidential Election will assist those efforts.

Shane Rattenbury, ACT Minister for Water, Energy and Emissions Reduction, also spoke and outlined some of the ACT Government's energy plans following the 2020 ACT election.

Prof Mark Z Jacobson of Stanford University delivered the 2020 ANU/ ACT Government Solar Oration and outlined how the world can transition to 100& renewables using wind, water and solar.

ANU Energy Update 3 December 2020

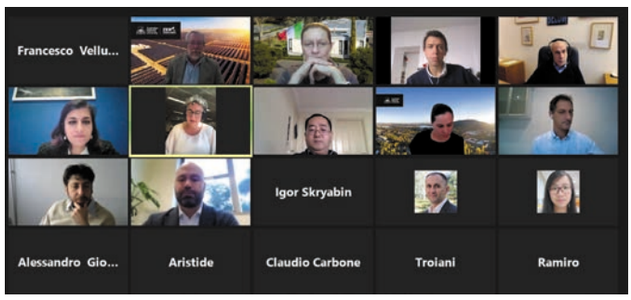
The annual ECI flagship event Energy Update was this year held in conjunction with the Energy Research Institutes Council for Australia (ERICA). Ian Cronshaw, formerly with the International Energy Agency, presented the IEA's perspective on the *World Energy Outlook* (WEO) 2020. He was followed by an expert panel comprising members of the Australian Energy Market Operator, ANU, Energy Efficiency Council, and Centre for Energy Futures at the University of Queensland.



The ANU Energy Update 2020 featured from top left, Ian Cronshaw, Nicola Falcon, Prof Kylie Catchpole, Prof Stephen Wilson (bottom left), Luke Menzel and Prof Ken Baldwin.

First Australia-Italy Hydrogen Workshop 9-10 December 2020

The ECI and Italy's National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) held their first joint workshop which explored their expertise in hydrogen and renewable fuels, and created foundations for future collaborations. The two-day gathering was organised with the support of the Australian Department of Foreign Affairs & Trade, and the Embassy of Italy in Canberra. It followed a Memorandum of Understanding ECI and ENEA signed in late 2019.



The first Australia-Italy workshop on hydrogen and renewable fuels featured researchers from the ANU and Italy's ENEA.

MISSION

A technician checks a mirror panel on the ANU Big Dish ANU.

A key solution to the challenge of climate change is a world-wide shift to low-carbon 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, security, 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

Photo credit: Dr James Prest

The ECI comprises more than 230 academic staff and their postgraduate research students, bringing the total complement to around 300 researchers.

The wider ECI membership meets every year at the Annual Business Meeting (ABM), which establishes the activity for the coming year.

ECI Executive

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

Professor Ken Baldwin – Director
ANU College of Science

Professor Sara Bice (*alternate Associate Professor Carolyn Hendriks*)
ANU College of Asia and the Pacific

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

Professor Lachlan Blackhall (*alternate Dr Sid Chau*)
ANU College of Engineering and Computer Science

Professor Kylie Catchpole (*alternate Dr Marnie Shaw)*
ANU College of Engineering & Computer Science

Professor Frank Jotzo (*alternate Dr Paul Burke*)
ANU College of Asia & the Pacific

Professor Yun Liu (*alternate Dr Annie Colebatch*)
ANU College of Science

Dr James Prest (Education Co-convenor, 2019-2020)
ANU College of Law

Dr Igor Skryabin – Research and Business Development Manager, Education Co-convenor
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 – Chair
Climate Change Authority, Australia

Ms Nicola Falcon – General Manager, Forecasting
Australian Market Energy Operator (AEMO)

Dr Bruce Godfrey – Principal
Wyld Group Pty Ltd

Professor Mark Howden – Director
ANU Climate Change Institute

Mr Gene McGlynn – Executive Director
Climate Change & Sustainability, ACT Government

Ms Fiona Wright – Group Manager
Strategic Safety and Risk, ActewAGL

EDUCATION

Master of Energy Change students at a social gathering, March 2020

Master of Energy Change

The Energy Change Institute coordinates the Master of Energy Change 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 practitioners and decision makers from Australia and overseas with the knowledge and skills to help lead the energy revolution.

The degree is equally relevant to those with a technical or non-technical background, as it bridges the gap between scientific and engineering aspects of energy with insights from the humanities, law and economics. It provides students 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 enables choices from 43 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.

Students must also choose one course from each of the following areas:

>Energy governance and law

>Energy policy and economics

>Science of climate change

>Sustainable systems/environmental problems.

In addition to the formal coursework, Master of Energy Change students can undertake in-depth research projects with experts from the ANU, and/or supervised internships with industry and government.

Students are also encouraged to participate in the wider activities of the ECI, which include a multitude of seminars, conferences and workshops at ANU engaging with government and industry on various energy topics.

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.

We continue to market the program via digital channels and are confident interest will continue to grow among domestic and international students. We continue to receive applications from across Australia, as well as the Asia Pacific, Middle East, Africa and the Americas.

EDUCATION

Professional Short Courses

Our flagship course, Energy Essentials for Professionals, was created for professionals across government and industry who are interested in the energy transition and who seek a comprehensive overview of the latest trends in energy technology, economics and policy.

In 2020 the move to an online teaching environment meant changes to our main offering. In previous years, most students were from the Canberra region. But shifting to a virtual campus allowed professionals from other parts of Australia to participate remotely, as previously they may not have been able to travel to the campus for the course. Professions represented included public servants from the ACT and NSW Governments, the Australian Department of Foreign Affairs and Trade, and representatives from the energy industry.

We ran three short courses in 2020: two for the general public, and one for about 30 members of the Australian Renewable Energy Agency (ARENA). Each week-long course covered:

- Economics of low-carbon energy
- Variable Renewable Energy Sources / Electrification
- Hydrogen as energy vector
- Energy Futures and Energy Security

We anticipate offering a mix of in-person and online courses in future.

Professional Short Course Convenor

Dr Igor Skryabin

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E igor.skryabin@anu.edu.au
W energy.anu.edu.au/energy-essentials-professionals-short-course

Joint winners of the Prosser Scholarship

Oscar Starmer and Tom Atkins were the joint winners in 2020 of the Jennifer and Ian Prosser Scholarship, which assists first-year ANU Master of Energy Change students. Worth $5,000 each, the scholarships are generously provided by the Prossers as they value higher education, an interdisciplinary approach to energy change and sustainability, and the need to support regional and rural students of Australia.

Oscar hails from the southern NSW coastal town of Moruya, while Tom is from Dungog in the state's Hunter Valley region. Oscar decided to study the ANU Master of Energy Change because he wanted to gain a better understanding of renewable energy, and use the electrification of transport and industry to help in the fight against climate change. He's the Board Secretary of SolarShare Canberra, a community-based solar energy project.

Tom works with ACT gas and electricity distributor Evoenergy, and has a background in environmental management in sectors including waste water and electricity distribution.

First GPG Australia Hydrogen Economy scholar to study storage options

The Global Power Generation (GPG) Australia Scholarship in the Hydrogen Economy is part of the leading renewable energy company's 20-year investment at the ANU worth $1.5 million that was announced in February 2020. The Institute and University are grateful to GPG for its commitment to helping train the next generation of renewable energy scholars.

Desy Prihardini will use the $20,000 GPG Scholarship to study hydrogen storage in liquid organic carriers.

"I am most interested in hydrogen as an energy vector as I think it has potential to be the solution for broadening the spectrum of decarbonizing the world's energy system," said Desy.

"This scholarship will not only provide support for me to complete the project I'm undertaking, but also motivate me to delve further into this field."

Desy has a background in chemical engineering, and will use the scholarship to boost her research skills in designing advanced chemical systems such as liquid organic hydrogen carriers (LOHCs).

These carriers are molecules which would enable hydrogen to be stored and transported in liquid form, which would make the energy vector more technologically and economically viable.

Desy is part of a project in the ANU Research School of Chemistry in which researchers are building a database of potential LOHCs based on the Jean-Claude Bradley Melting Point Dataset.

Developing efficient and effective hydrogen storage technologies will help support the growth of the hydrogen economy in Australia, including as a potential export industry to countries such as Japan, South Korea and Germany, which have all expressed interest in Australian hydrogen.

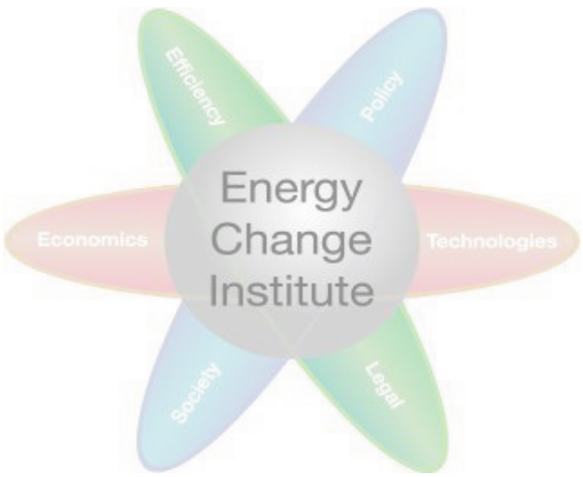
Desy, from Surabaya, Indonesia, has transferred from the Master of Energy Change program to the Master of Energy Change (Advanced) stream.

RESEARCH

The expanded ECI research program covers a broad spectrum from energy science and engineering to implementation expertise in the economic, legal, sociological and policy issues surrounding energy change. This broad portfolio of research activity is unique in the country.

The ECI continues to add new researchers to its portfolio. The number of staff members is approximately 230, which together with postgraduate students brings the total complement to around 300 researchers.

In 2020, the ECI portfolio comprised 20 research clusters.



> Artificial Photosynthesis

> Carbon Capture, Utilisation & 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

> Hydrogen Economy

> 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

Net zero by 2050 only possible if renewables ramp up: ANU study

Australia will not achieve net zero emissions until well after 2050 at the rate emissions are declining, experts from The Australian National University (ANU) warn.

However, they argue that by accelerating deployment of solar and wind, Australia can reach 80 per cent emissions reductions within 20 years at low or negative cost. This would place Australia within striking distance of net zero in 2050.

The latest official data from the Clean Energy Regulator shows Australia is continuing to install solar and wind power much faster per person than any other country.

Professor Andrew Blakers said Australia has declining electricity emissions and declining electricity prices, as more renewables feed into the network.

“Around seven Gigawatts of new solar and wind was added in 2020, which was deployed four times faster per capita than in Europe, China, Japan or the United States,” Professor Blakers, from the ANU School of Engineering, said.

“Around seven Gigawatts of new solar and wind was added in 2020, which was deployed four times faster per capita than in Europe, China, Japan or the United States.”

“Gas energy is declining because it cannot compete with solar and wind.”

According to new data from the Department of Industry, Science, Energy and Resources, Australia’s carbon emissions declined by 4.4 per cent in the year to September 2020.

Professor Blakers said the decline is primarily due to the deployment of solar and wind in the electricity sector and the pandemic’s hit to transport.

“Australia has a ‘golden opportunity’ to be much more ambitious with its zero emissions target,” he said.

“Fossil fuel energy causes 80 per cent of Australia’s emissions. We can readily reach zero fossil energy by 2040, if we double the average rate of solar and wind deployment.”

Energy expert Professor Ken Baldwin said wholesale electricity prices halved in the past year compared with the average of the previous four years, coinciding with high levels of new solar and wind power.

“If we install solar and wind faster, then emissions fall faster and electricity prices will stay low,” he said.

Associate Professor Matthew Stocks said governments can ensure that emissions continue to fall on the back of solar and wind energy by enabling adequate electricity transmission and energy storage.

“Balancing variable solar and wind is straightforward using off-the-shelf techniques; for example, stronger long-distance transmission - to smooth out variable local weather - pumped-hydro and battery storage and demand management,” Associate Professor Stocks, from the ANU School of Engineering, said.

“Australia has 4,000 potential pumped hydro sites with combined energy storage potential of 180 terawatt-hours, which is about 300 times more than required to support 100 per cent renewable electricity.

“About a dozen large pumped hydro systems are under serious consideration, while the Snowy 2.0 system is under construction.”

Professor Blakers said that once electricity generation has low emissions, other sectors such as transport need to be electrified.

The authors’ study is *Australia: 80% emissions reduction by 2040 Technical Paper.*

Photo: ANU Wind Energy course students at the Capital Wind Farm.

Artificial Photosynthesis

The Artificial Photosynthesis research effort at ANU continues to focus on both the mechanism and mimicry of water-splitting in nature, which is the fundamental process whereby sunlight is converted to storable energy. Splitting water into hydrogen and oxygen is the heart of the new “Green Hydrogen” technologies.

Significant advances have been made by the ANU-University of Wollongong (UoW) joint project, “Bio-Inspired Hydrogen Generation by novel Bubble Free Electro-Catalytic Systems”. This project received $600,000 in funding from ARENA in 2018 and was led by the late Emeritus Professor Ron Pace. Water splitting in nature occurs at the manganese-containing catalytic centre, known as the Oxygen Evolving Complex (OEC) (see adjacent page).

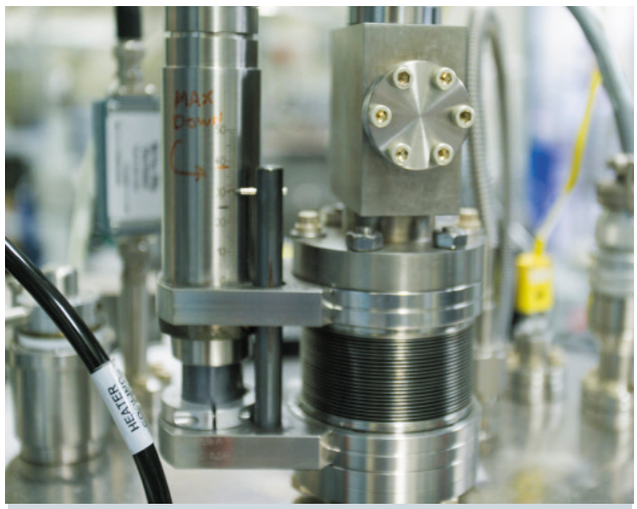
Recent advances at ANU have revealed key understandings of this natural electrolysis process, which is the most efficient known. These are then used as an engineering principle in artificial photosynthesis. Prof Pace, Prof Rob Stranger and collaborators have designed novel chemical surfaces (electrodes), mimicking key structures related to the OEC. Using these and new ‘Bubble Free’ Gortex electrodes, developed at the UoW, efficient hydrogen generation, sourced from water and renewable electricity, will become more efficient and also avoid the use of rare and expensive metals like platinum.

A more recent development utilizes Edge-Functionalized-Graphene (EFG). Recent experimental and computational results concur on the catalytic importance of Ca in the water splitting process in both the natural and biomimetic systems.

Electron Paramagnetic Resonance
Australia’s first high-field Electron Paramagnetic Resonance facility, under the stewardship of ECI member Dr Nick Cox, is now been fully enabled and enhanced and forms part of the Magnetic Resonance Facility of the ANU. These facilities are being used in tandem with the RSC’s uniquely capable optical spectroscopy lab to target artificial photosynthesis, structural biology and materials science developments.

In 2019 Dr Cox won an ARC grant in artificial photosynthesis to study photosynthetic extemophiles (organisms that photosynthesize under extreme conditions of temperature, light or pH) and use understanding of these systems to develop new water splitting catalysts as well as to explore the ‘quantum toolbox’ of photosynthetic reactions centers. Dr Nick Cox, Dr Robin Purchase and Professor Elmars Krausz have published a number of papers analysing the spectacular spectroscopic properties of both ‘normal’ reaction centers and those of extremophiles.

Research highlights
Associate Professor Tsuzuki co-authored a paper, published in *Applied Sciences* in 2019, that considered the prospects of developing a commercially-feasible water electrolyser with 95–100% energy efficiency at the cells in the near future. It showed that at least a 5–10% improvement in energy efficiency over the best, existing commercial water electrolysers is needed, and can be achieved by the elimination or mitigation of the direct and indirect energy losses arising from bubble formation in electrolysers.

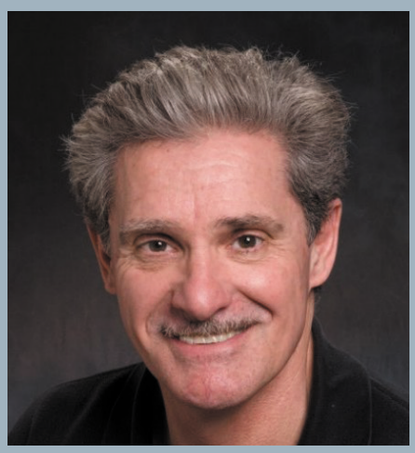


Cluster Members:
Convenor, Professor Elmars Krausz
Dr Nick Cox
Professor Mark Humphrey
Dr Hermant Kumar Mulmudi
Professor David Ollis
The late Emeritus Professor Ron Pace
Dr Robin Purchase
Professor Robert Stranger

Associate Professor Tsuzuki, Professor Pace, and Professor Stranger were among co-authors of a paper that examines the phenomenon of ‘bubble-free’ electrocatalytic oxygen evolution from water, using a gas diffusion electrode that extracts oxygen as it is evolved. It represents an important step in the development of bubble-free electrodes, which promise to improve water electrolysis efficiency, revolutionise electrolyser system design, and lower capital and operational costs. The paper was published by *Sustainable Energy & Fuels*.

Members also had papers published by journals including *Photsynthetica*, *Biochimica et Biophysica Acta (BBA)-Bioenergetics*, and the *Australian Journal of Chemistry*.

Vale Emeritus Professor Ron Pace



The late Emeritus Professor Ron Pace made major contributions to understanding photosynthesis, both natural and artificial. The following is a selection of some of the projects in which he was involved from 2018-2020, alongside fellow Chief Investigators, Prof Robert Stranger and Associate Professor Takuya Tsuzuki.

The ARENA-funded, ANU-University of Wollongong (UoW) joint project, "Bio-Inspired Hydrogen Generation by novel Bubble Free Electro-Catalytic Systems", involved designing and demonstrating a bubble-free anodic water oxidising system. It uses componentry inspired by the Oxygen Evolving Centre in Photosystem II. This would be central to efficient electrolytic H_2 generation from water at near neutral pH. Detailed computational chemical studies accompanied this, on the structure and catalytic mechanism likely operating within the bio-mimetic system. The key experimental components, with functioning assembly of the bubble-free electrode system, with a-biological and bio-ispired catalytic surfaces, has been demonstrated. The organic substrate we have most recently used is edge functionalised graphene (EFG), which the computational work concentrates on (Fig 1). Importantly, both the experimental and computational results agree on the catalytic importance of Ca, as is the case in natural water oxidising site (see below).

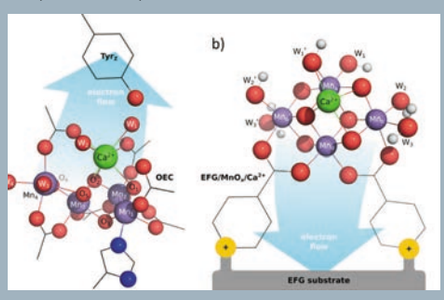


Fig 1 a) Shows the local molecular structure of the PS II OEC. Electron flow to the photo-oxidised P680 Centre occurs through the Tyr_z link. The likely surface of the bio-inspired EFG electrode is shown in b). The EFG substrate is incorporated onto a Ni mesh electron acceptor.

The work has generated eight manuscripts, some published, in press, submitted, or in preparation. A summary of the publications below are a tribute to the wide-ranging and innovative efforts made by Prof. Pace and his collaborators.

Manuscripts (1) & (2) describe work that occurred in parallel with the ARENA project, but was not directly funded by it. It has substantial importance for the project generally and was directed by CI's Assoc Prof Takuya Tsuzuki and Prof Gerhard Swiegers. It concerns the detailed characterisation of a range of Ca/Mn-oxo systems, as potential anodic water splitting catalysts at practical, near-neutral pH (~ 12). Importantly the photo-enhancement of catalytic activity under visible range light illumination was studied.

Manuscript (3) has major relevance for the whole project insofar as it provided the parameters under which to prepare and test the systems that formally addressed the milestones. It describes the assembly and detailed characterisation of the bubble free Gortex electrode system.

Manuscripts

(1) "Photo-Electrochemical Oxygen Evolution Reaction by Biomimetic $CaMn_2O_4$ Catalyst" (Published in *Applied Sciences* 2019, 9, 2196)

(2) "Comparative Evaluation of the Structural and Other Features Governing Photo-Electrochemical Oxygen Evolution by Ca/Mn Oxides" (Published in *Catalysis Science and Technology*, 2020, 10, 2152)

(3) "Insights into the Phenomenon of 'Bubble-Free' Electrocatalytic Oxygen Evolution from Water" (Accepted by *Sustainable Energy & Fuels*)

(4) "New Insights into the Operation of the Photosystem II- Oxygen Evolving Centre (PSII-OEC). A Bio-Inspired, Water Oxidation Catalyst that is 1/10th – 1/20th as Active as the PSII-OEC in Neutral Water" (Submitted to *Energy and Environmental Science*)

(5) "Interaction of graphene, MnO_x, and Ca^{2+} during biomimetic, 'bubble-free' electrochemical oxygen evolution at mild pH' (G. Tsekouras et. al., ready for submission)

(6) "The Prospects of Developing a Highly Energy-Efficient Water Electrolyzer by Eliminating or Mitigating Bubble Effects" (G. Swiegers et. al., Submitted *Energy & Environmental Science*)

(7) "Electronic structure modelling of edge-functionalisation of graphene by MnO_x particles" (R. Terrett submitted *Phys. Chem. Chem. Phys*)

(8) "Towards water oxidation at graphene-bound Mn_xO_y and $Mn_xO_yM^{2+}$ particles" (R. Terrett submitted *Phys. Chem. Chem.*) Attachment 9

Carbon Capture, Utilisation and Storage (CCUS)

Carbon Capture, Utilization, and Storage (CCUS) involves the capture of emitted carbon dioxide (CO_2), either from point source emitters or directly from the atmosphere, followed by recycling in usable materials ("utilization") or disposal in porous rocks deep underground ("storage"). Nearly all pathways identified by the Intergovernmental Panel on Climate Change that limit climate-change induced temperature rise to less than 2°C rely on large-scale diversion of carbon emissions away from the atmosphere and instead into permanent storage. Storage in underground formations is a relatively mature technology with a large CO_2 containment capacity worldwide, while utilization in useful market-competitive products provides favourable financial incentives.

CCUS can be used to reduce or eliminate carbon emissions from traditionally carbon-intensive fossil fuel-based electricity generation, as it provides potential to capture the produced CO_2 and store it before it enters the atmosphere; and CCUS 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. CCUS can be a negative emissions technology when coupled with direct air capture or bioenergy production. Financial incentive for carbon emissions reduction, elimination, and negative emissions schemes remains a challenge.

Subsurface Carbon Storage

In geologic sequestration, the big questions lie in the long-term security of the proposed underground storage reservoir. A main goal during CO_2 injection schemes is to limit the fraction of upwardly mobile CO_2 by trapping small bubbles of CO_2 via capillarity within the tortuous microscopic structure of the porous reservoir rock, and by promoting the dissolution of CO_2 into the reservoir water. These processes are dependent on the interfacial interactions and configurations of the injected CO_2, reservoir water, and host rock surfaces. Using the unique 3D microscopy capabilities of the ANU National Laboratory for X-ray MicroComputed Tomography (CTLab), Drs Anna Herring and Mohammad Saadatfar have conducted 3D image-based high-pressure high-temperature core-flooding studies of water and CO_2 in a supercritical state ($scCO_2$), exploring the trapping potential and fluid distributions in various rock formations over many injection cycles. These studies investigate fluid flow behaviour in model isotropic quarry sandstones, as well as heterogeneous reservoir rocks from pilot storage sites in the Otway basin in Victoria and Queensland's Surat basin, with support of Australian National Low Emissions Coal Research & Development (ANLEC R&D).

Mineral Carbonation

Gaseous CO_2 can react with metal oxides (mainly calcium and magnesium) to produce carbonate minerals. These mineral products can be considered as both CO_2 storage and utilization opportunities; for example, mineral carbonation occurs passively in mine tailings weathering, but the process can also be engineered to produce useful and economically viable building materials with favourable structural characteristics. In order for mineral carbonation to serve as a permanent and effective sink for CO_2, the carbonation reaction kinetics and products need to be accurately characterized, as well as the 3D structural influences on both kinetics and products for granular materials. Dr Anna Herring, Dr Mohammad Saadatfar, and Professor Penny King have developed and demonstrated an experimental pipeline to investigate these problems, using a novel combination of mineralogical characterization (via diffuse reflectance Fourier transform infrared spectroscopy and X-ray diffraction) and structure/density distribution characterization via 3D X-ray MicroComputed Tomography. The pipeline utilizes non-destructive techniques to provide temporally resolved observations of reaction progress and reaction products, enabling the ability to leverage structural design and curing protocols to produce desired material characteristics.

Cluster Members:

Convenor, Professor Adrian Sheppard
Associate Professor Rowena Ball
Professor Amanda Barnard
Professor Justin Borevitz
Professor Stewart Fallon
Dr Anna Herring
Associate Professor Penny King
Professor Mark Knackstedt
Dr Mohammad Saadatfar
Professor Tim Senden
Professor Sean Smith
Dr Xiaolin (Shannon) Wang
Dr Nicholas White
Dr Zongyou Yin

Figure 1. Supercritical CO_2 ($scCO_2$, red) distribution after injection into a previously water-filled sandstone core. Processed experimental image acquired by Dr Anna Herring via the ANU CTLab.

Thermodynamic optimization of CO_2 separation

Innovations in carbon dioxide separation and regeneration are critical because these steps currently account for around 80 per cent of the cost of process decarbonation. Associate Professor Rowena Ball from the Mathematical Sciences Institute developed a new technology, Endex calcium looping, for separating CO_2 from fuels and flue gases, using mathematical modelling and computational simulation. Endex technology reduces the cost of process decarbonation and has been commercialized by an Australian and European-British company, Calix Ltd. Thermodynamic analysis carried out by Ball shows an efficiency gain – or op-ex reduction – by a factor of two or more for Endex separation over conventional methods. In addition to reducing CO_2 emissions, the technology has further impact: fitted to power plants co-fired with biomass it can effect net removal of CO_2 from the atmosphere.

Energy & Security

The global energy landscape underwent a profound transformation from 2019-2020. The COVID-19 pandemic, among other developments, has reshaped the strategic environment, requiring a rethink of traditional supply and demand networks, protection of critical infrastructure, and strategies to address the environmental and human security repercussions of climate change and energy transitions.

ECI Energy and Security cluster members examine these issues from an interdisciplinary perspective, actively collaborating with partners from industry, government, policy, and academic, both in Australia and abroad. Members engaged public servants via the Executive Professional program run by the ANU National Security College, and briefed parliamentarians on energy, climate-driven insecurity, and international relations.

Recent research addressed:

- Global energy governance
- Coal divestment in Japan
- Oil-driven development in Saudi Arabia
- China's energy transition

Congratulations to Energy and Security cluster member Dr Liz Boulton, who completed her PhD on "Climate and Environmental Change: Time to Reframe Threat?" in June 2020.

Members' expertise also featured across Australian and international media, including The Conversation, Bloomberg, Australian Foreign Affairs, the Lowy Interpreter, and ABC Radio National. Alongside solar PV and wind expert Professor Andrew Blakers, previous Energy & Security Cluster Convenor, Dr Jennifer Hunt, appeared in the Energy Revolutions episode of the ABC-TV series *The Great Acceleration*.

Transformation of regional relationships

As states around the world transition to low carbon societies, new opportunities and challenges for Australian collaboration with regional partners have emerged. Dr Christian Downie and Associate Professor Llewelyn Hughes identified potential cracks in Japan's historically strong financing of international coal plants, arguing that the government is starting to pay greater attention to global criticism over the coal industry. Meanwhile, opportunities for collaboration on low-carbon technologies with Japan, as Associate Professor Hughes argued, have increased, not only in hydrogen and carbon reuse, but also capture, utilisation, and storage.

Another highlight was Professor John Blaxland's SWOT analysis of Australia's geopolitics for the Australian Strategic and Defense Studies Centre's Centre of Gravity Series, which called for a 'grand compact' with South Pacific countries to address climate change insecurity, among other shared threats. This proposal was presented to the Parliamentary Joint Committee on Foreign Affairs, Defence and Trade as part of its Inquiry into strengthening Australia's relationships in the Pacific region to meet current and emerging opportunities and risks.

Cluster Members:

Convenor, Dr Jennifer Hunt
Adjunct Professor Chris Barrie
Professor John Blaxland
Dr Elizabeth Boulton
Professor Roger Bradbury
Dr Christian Downie
Professor Quentin Grafton
Dr William Grant
Associate Professor Llewelyn Hughes
Dr Jessie Moritz
Professor Rory Medcalf
Professor Brendan Taylor
Dr Yixiao Zhou

The Cluster thanks Dr Hunt for her time as convenor, and welcomes Dr Moritz as the new convenor in 2021.

Dr Jessie Moritz (right) appeared on ABC-TV News on 15 September 2019 to discuss the attack on the Abqaiq oil refinery in Saudi Arabia.

Protection and Disruption of Global Energy Supply Chains

These supply chains came under repeated threat in 2019 and 2020. As a result, many states have looked inward, encouraging the movement of manufacturing home from abroad. But as Associate Professor Llewelyn Hughes and co-author Professor Andreas Goldhau noted in a commentary in *Nature*, this process of de-globalisation will raise the cost of low-carbon products, and, "If nations pursue economic security above all else, low-carbon technologies will be exposed to geopolitical risk. Global supply chains can become a proxy for geopolitical rivalries".

Nowhere was this clearer than in the September 2019 missile strike on oil refineries in Saudi Arabia, disrupting almost 5% of global oil production. Dr Jessie Moritz was featured on international TV news to interpret these events, examining the tensions between Saudi Arabia, Iran, and Houthi rebels in Yemen that led to targeting of oil infrastructure and energy trade chokepoints in the Persian Gulf. Less than six months later, the Saudi-Russian oil price war combined with the pandemic caused the global collapse of oil futures. These questions – non-renewable energy insecurity as well as divestment and climate change – are fundamental to Australia's own security, as Dr Hunt highlighted in a presentation the 2019 Australian Defence Force Rapid Force Projection Conference.

Energy Economics & Policy

In 2020, cluster members' various activities included the world's largest study of carbon pricing schemes, an International Monetary Fund report chapter on mitigating climate change, plus a city-specfic study on impacts of time-of-use electricity tariffs.

Members' expertise is concentrated in the Crawford School of Public Policy and the Research School of Economics, drawing on members' strengths in economics and political science.

The Centre for Climate and Energy Policy anchors a network of researchers providing insights on the economics of climate change, its implications for public policy, and the design of policies for zero-carbon energy systems.

Associate Professor Paul Burke and Professor Frank Jotzo co-authored the first major global study on the effectiveness of carbon pricing schemes at reducing emissions. The paper is useful for informing the design and improvement of emissions reduction strategies in Australia and elsewhere. The paper was written with Dr Rohan Best of Macquarie University and published in *Environmental and Resource Economics*.

Professor Warwick McKibbin co-authored Chapter 3 of the International Monetary Fund's *World Economic Outlook*, titled Mitigating Climate Change: Growth- and Distribution-Friendly Strategies'. He also co-authored a paper on 'Global economic and environmental outcomes of the Paris Agreement' in *Energy Economics.*

Professor McKibbin also contributed to Efficient, Effective and Fair Climate Policy: A Discussion Paper published in June 2020 by the Academy of the Social Sciences in Australia. The paper addressed how to achieve greenhouse gas reductions in a way that causes least cost to the economy, promotes innovation, and is fair.

Dr Lee White published a paper in *Nature Energy* on the health and financial impacts of time-of-use electricity tariffs. The research found that these tariffs can lead to disproportionate increases in electricity bills for households with elderly and disabled household members. Dr White also wrote a commentary in *Nature Behavioural and Social Sciences* about the energy transition and the world's response to COVID-19.

Professor Frank Jotzo and Dr Thomas Longden conducted analysis on evaluating stimulus options in response to the COVID-19 crisis. They identified a number of energy-sector priorities for Australia such as the fast-tracking of renewable energy zones. The analysis was released as a Centre for Climate and Energy Policy Working Paper and presented in *The Conversation*. The pair, along with Dr Mousami Prasad and Richard Andrews, also co-wrote a study on green hydrogen nearing the goal of $2/kg, which was featured in the 28 October edition of the Australian Renewable Energy Agency (ARENA) Insights newsletter.

Cluster Members:

Convenor, Associate Professor Paul Burke
Dr Imran Habib Ahmad
Dr Emma Aisbett
Professor Robert Breunig
Professor Bruce Chapman
Honorary Associate Professor Simon Corbell
Professor Robert Costanza
Dr Priya Dev
Dr Thang Do
Associate Professor Christian Downie
Dr Reza Fazeli
Dr Jorrit Gosens
Professor Quentin Grafton
Associate Professor Carolyn Hendriks
Honorary Professor John Hewson
Associate Professor Llewelyn Hughes
Dr José Iria
Professor Frank Jotzo
Professor Kaliappa Kalirajan
Associate Professor Andrew Kennedy
Associate Professor Ida Kubiszewski
Dr Thomas Longden
Professor Warwick McKibbin
Adjunct Professor Robert McMullan
Dr Jessie Moritz
Dr John (Jack) Pezzey
Associate Professor Ben Phillips
Dr Mousami Prasad
Professor Israr Qureshi
Associate Professor Maria Racionero
Professor Martin Richardson
Honorary Associate Professor Hugh Saddler
Professor Ligang Song
Professor David Stern
Dr Bjorn Sturmberg
Dr Lee White
Dr Paul Wyrwoll

Dr Jorrit Gosens and Professor Jotzo published a paper in *Environmental Innovation and Societal Transitions* on China's post-COVID-19 stimulus, and Dr Jessie Moritz published a piece in the *British Journal of Middle East Studies* on how oil wealth in the Middle East is stimulating the participation of civil society organisations in national discourse. She appeared in several international media outlets.

Bringing intermittent renewables into electricity markets created various challenges, as Professor David Stern and colleagues argued in their paper in *The Electricity Journal*.

Energy Efficiency

Energy efficiency is the lowest cost strategy to reduce greenhouse gas emissions. According to the International Energy Agency, effective energy efficiency measures could deliver over 40% of the abatement required by 2040, to be in line with the Paris Agreement.

A range of ANU academics across three colleges undertake research in the fields of energy efficiency and their work has informed the recently developed Energy Management Strategy, part of the ANU campus masterplan. The strategy outlines a plan to adapt campus energy systems to become more efficient, flexible, responsive and decentralised.

The Energy Management Strategy was developed through a collaboration between Facilities and Services (F&S) and the Energy Change Institute, and supported by work carried out by students of the Energy Change Institute.

One of the key components of the strategy will be an Energy Dashboard, where real-time data from a total of 743 electricity meters, 56 water meters and 91 thermal meters across campus will provide water and energy consumption information for buildings and infrastructure.

F&S have set up a rolling program to use this data to create targeted energy efficiency programs for 59 buildings every two years. In 2021, 32 buildings will be targeted. In addition, gas boilers requiring replacement will be replaced with chillers if feasible, to phase out gas. The installation of a new water misting system in one of the chillers in the John Curtin School of Medical Research in 2020 has seen significant energy savings.

The Energy Dashboard will also be used for research, teaching and learning.

Sustainable building design at the ANU

Using the ANU Below Zero initiative as a guide, Facilities and Services, in conjunction with architectural firm Lyons, have created a masterplan for planned buildings for the College of Health and Medicine. The plan provides a framework to ensure integrative design around sustainability is embedded in the Architectural and Engineering response.

A pragmatic and holistic design approach will ensure the facilities are easy to maintain with a best-in-class approach to sustainability. The proposed building concept is fossil fuel-free, highly energy efficient, powered by renewables, constructed with low carbon materials and with the ability to offset carbon.

According to the International Energy Agency, effective energy efficiency measures could deliver over 40% of the abatement required by 2040, to be in line with the Paris Agreement.

RachelW1/Wikipedia

Cluster Members:

Convenor, Dr Marnie Shaw
Dr John (Jack) Pezzey
Dr Digby Race
Honorary Associate Professor Hugh Saddler
Mr Tom Worthington

No real change in Australia's energy productivity between 2009-2019

Energy productivity is the ratio of economic output to energy consumption. Increased energy productivity is needed to reduce GHG emissions. In 2015, Australian governments adopted the National Energy Productivity Plan, with the goal of increasing Australia's energy productivity over the 15 years to 2030 by 40 per cent.

Honorary Associate Professor Hugh Saddler analysed, in a Centre for Climate & Energy Policy (CCEP) working paper, trends in Australia's energy productivity from 2009 to 2019, across individual economic sectors. The paper found that there was virtually no change in the efficiency with which energy was used by final consumers between 2015 and 2019, though some sectors increased and some decreased.

If the substantial amount of energy used by energy industries to convert raw energy into energy commodities useful to consumers (e.g. electricity), are included in the calculations, then an increase in total energy productivity is observed.

However, this is not due to increased economic output per unit of energy used, but rather due to the shift towards renewable electricity and away from very energy intensive generation of electricity from coal.

Energy for Development

The energy trilemma refers to the three pronged nature of global energy issues, the desire to achieve energy security while addressing the environmental implications of energy production, and the need to provide energy access to those who don't have it. 840 million people lack access to electricity and over 2.8 billion people lack access to clean cooking technologies. Addressing this issue is a complex task that requires input from a broad spectrum of research disciplines, thus the energy for development cluster is an interdisciplinary group of researchers spanning across the ANU working on a broad variety of issues.

Associate Professor Paul Burke in the ANU Crawford School of Public Policy has been working with colleagues on energy access and the uptake of renewable energy in Southeast Asia and India with two papers in *Energy Policy*. One covered the recent take-off of investment in solar power in Vietnam, the second assessed the slow adoption of solar and wind energy in Indonesia compared to India's rapid uptake.

Also in the Crawford School, Professor David Stern was funded by the UK Department for International Development to develop a policy brief for the Energy for Economic Growth Programme on prepaid electricity metering in developing countries. Pre-paid electricity meters are expanding rapidly across the developing world and are seen as a solution to the non-payment of bills, electricity theft, and corruption. It has been projected that an additional 126 million pre-paid electricity meters will be rolled out between 2016 and 2026, with investments totalling US $11 billion, making this a growth area for investigation.

Dr Lily O'Neill from the Centre for Aboriginal Economic Policy Research & Energy Change Institute is a major part of the ANU Grand Challenge: *Zero-Carbon Energy for the Asia-Pacific Grand Challenge* (ZCEAP) project and published several papers on how to ensure indigenous peoples benefit from large scale renewable energy projects. Identifying both the opportunities and risks of these projects is critical in the Australian context and has implications for indigenous groups globally.

Another ZCEAP member, Dr Thomas Longden, published several pieces in the media on how green energy, particularly the production of hydrogen from renewable energy, can address both the major components of the energy trilemma while also having significant economic benefits.

Work on the integration of energy markets among ASEAN countries has been led by Professor Budy Resosudarmo. A paper in the *Singapore Economic Review* analyzed the impact of an energy subsidy reduction policy in ASEAN, particularly in terms of economic growth, environmental improvement and welfare distribution. The research concluded that countries such as Indonesia and Malaysia, stand to gain from eliminating their subsidies with likely increases in GDP coupled with reduced CO2 emissions.

Looking at Africa, Edwina Fingleton-Smith published work taking a critical view of expectations that energy access for poor people will automatically lead to increases in productivity.

Cluster Members:

Convenor, Dr Edwina Fingleton-Smith
Professor Sara Bice
Associate Professor Paul Burke
Associate Professor Jane Golley
Dr Jorrit Gosens
Associate Professor Alastair Greig
Professor Stephen Howes
Professor Frank Jotzo
Dr Thomas Longden
Dr Jessie Moritz
Dr Lily O'Neill
Dr Arianto Patunru
Professor Israr Qureshi
Dr Digby Race
Professor Budy P Resosudarmo
Dr Abidah Setyowati
Dr Jeremy Smith
Professor David Stern
Dr Yixiao Zhou

Highlighting the complex array of factors beyond energy access that influences peoples business decisions, she argues a more nuanced understanding of energy, and the interlinked role it plays in society will lead to more effective investments.

Dr Jorrit Gosens has been working on the development of clean energy production in the global south finding that China will increasingly become a leader not a follower in the global energy transition using their Concentrated Solar Power industry as an example. His other research has shown that levels of clean energy technologies in South-South trade, which were relatively low up until the first half of the 2010s, have become entirely comparable to North-North or other trade flows in recent years.

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.

Energy Regulation & Governance

The Regulation and Governance cluster 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 and regulation can raise barriers to the clean energy transition.

Our 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. We approach these vital questions on several scales — international, comparative, and at national and sub-national levels. Our projects involving energy law in Asia region position us well to contribute to the ANU Grand Challenge: *Zero-Carbon Energy for the Asia-Pacific* research project.

Renewable Energy mega-projects

Researchers in the cluster have been examining the implications of Gigawatt scale renewable energy mega-projects such as the Asian Renewable Energy Hub in the Pilbara (Western Australia) and the Suncable project (Northern Territory) to supply energy to Asia via large HVDC cables, or by export of hydrogen carrying chemicals.

The legal and justice issues raised by energy interconnectivity projects in Asia was the subject of a paper presented by Dr James Prest to the Asian Law Institute (ASLI) Conference at the NUS Singapore, Faculty of Law. A paper on international trade in hydrogen was published in *Energy* by Dr Lee White, Dr Wenting Cheng and Dr Lily O'Neill (and others) which examined boundaries of emissions certification systems.

Dr O'Neill and Dr Janet Hunt of the Grand Challenge team examined whether and how First Nations communities can best benefit from recently proposed Gigawatt-scale renewable energy generation in the NT and WA. Their papers have drawn from on experience from extractive industry agreement making and disputes over native title in relation to conventional energy projects.

Asia Pacific projects

Between 2018-2020, Professor Neil Gunningham and Associate Professor Christian Downie worked on the Department of Foreign Affairs & Trade-funded project 'Harnessing financial markets and institutional investment to increase the penetration of clean energy in the Asia Pacific' ($950,000). Prof Gunningham has published papers concerning the role of the fossil fuel divestment movement in climate change mitigation, and the role of financial markets in such mitigation. Assoc Prof Downie published a paper on divestment trends in Japan's international coal businesses, and a broader article on energy regulation in *Global Energy Governance*.

Energy poverty remains a key global challenge. For example, in Indonesia, around 25 million people are still without electricity access, and many live in geographically isolated areas and remote places. Dr Abidah Setyowati published multiple papers examining how private climate finance can be mobilised for renewable rural electrification in Indonesia. Another paper led by University medallist Hilman Fathoni (with Drs Setoyowati and Prest) examined energy justice questions around renewable energy projects on Sumba Island.

Cluster Members:

Convenor, Dr James Prest

Professor Sara Bice

Dr Wenting Cheng

Professor Katherine Daniell

Dr Thang Do

Associate Professor Christian Downie

Professor Peter Drahos

The late Professor Thomas Faunce

Dr Jorrit Gosens

Professor Neil Gunningham

Associate Professor Llewelyn Hughes

Professor Andrew MacIntosh

Dr Lily O'Neill

Dr John (Jack) Pezzey

Dr Hedda Ransan-Cooper

Dr Abidah Setyowati

Dr Esme Shirlow

During 2019-20 cluster members worked on many projects involving hydrogen and biomethane (renewable gas). How Australia's hydrogen strategy links up or conflicts with those of other East-Asian nations has been examined in work by Dr Jorrit Gossens. Australia's National Hydrogen Strategy and the Technology Investment Roadmap were subjected to in-depth comparison with hydrogen strategies of the EU and Germany, published in *Oil, Gas and Energy Law* (with J. Petit and J. Woodyatt).

Initial industry collaboration by the ECI on renewable gas projects involving Global Power Generation/Naturgy and Energy Developments Ltd led to several publications, grants and collaborations including the GPG Hydrogen Scholarship. A major report funded by the Australian Department of Industry, Science, Energy & Resources examined Regulatory Frameworks and Standards for Grid Injection of Biomethane in Australia. This was completed during 2019 by Drs Prest and Igor Skyrabin.

Drs Skryabin & Prest's collaboration with Evoenergy led to a paper at the International Conference on Hydrogen Safety considering the viability of reuse of ACT natural gas distribution network as a hydrogen distribution network, (pub. *Int. J Hydrogen Energy*). Consultants ITP Renewables drew upon expertise of ANU researchers including Dr Prest for their report into policy options for renewable gas (hydrogen and biomethane) commissioned by the ACT government during 2020.

Vale Professor Thomas Faunce

Thomas Alured Faunce, 8 August 1958 - 7 July 2019.

Professor Tom Faunce was an inaugural member of the ANU Energy Change Institute, representing the Law School on the ECI Executive Committee. He passed away suddenly but peacefully at home on 7 July 2019. His passing is an immense loss for ANU and its community.

Tom exemplified many of the interdisciplinary ideals of the ECI. He was qualified as both a medical doctor and a lawyer. Pre-academia, he practiced in both fields. He was Associate to Justice Murphy of the High Court and worked as solicitor with Mallesons (Canberra) and Freehills (Sydney).

He held joint professorial positions in the College of Law and College of Medicine. He was the winner of five ARC Discovery Grants and an ARC Future Fellowship. His numerous research outputs reflected his diverse background. Although a lawyer, he was not afraid of participating in discussions of physics or chemistry. Health law and bioethics were his main field of academic endeavour.[1]

As an ARC Future Fellow, Tom studied the potential and the risks of nanotechnologies. This project explored how nanotechnology could help solve the great public health and environmental challenges of our time. This included examining use of artificial photosynthesis to produce renewable fuel and fertiliser. He elaborated upon these ideas in the book *Nanotechnology for a Sustainable World*.[2]

In *Here's to hydrogen: Australia is missing the potential of solar fuels,* he wrote: "Many energy policy makers and funding agencies consider that solar energy research and development is all about photovoltaics… Yet cyanobacteria and plants have been storing solar energy in chemical bonds for several billion years and the scientific challenge of improving upon that whole process is perhaps the most important of our time."

Tom argued for a national research funding program for molecular solar fuels similar to the US Joint Center on Artificial Photosynthesis (JCAP) and the Solar H_2 network in Europe. He wrote "It is high time Australia set up its own dedicated national solar fuels project."[3]

Tom took this idea further, gaining funding and agreement to bring together an international network of the leading scientists in the field. They met in August 2011 at the spectacular World Heritage-listed Lord Howe Island for the first international conference on the Global Artificial Photosynthesis (GAP) project. With co-authors including Peidong Yang (University of California) and Daniel G. Nocera (Harvard and MIT), the proceedings were published in the Royal Society for Chemistry's journal *Energy Environmental Science*.[4]

A follow up meeting of the network was led and organised by Tom in July 2014 at the Royal Society's property in Buckinghamshire, Chicheley Hall. Papers were published as a special edition of *Interface Focus*, a peer-reviewed journal of the Royal Society.[5]

As ANU Vice-Chancellor, Professor Brian Schmidt explained: "He was always sharp of mind and did not shy from asking the most complex and challenging questions. He leaves a powerful legacy. He will be missed dearly."

Tom's 2019 novel *Split by Sun* also explored the possible contribution of artificial photosynthesis as well as notions of Ecocide and Earth stewardship.[6] Tom stated that in some ways, although written for fun, this book was the culmination of his life's work as it combined ethical and scientific questions.

Apart from being a man with many big ideas spanning a huge breadth of disciplines, Tom was a generous man who mentored many students and ECRs. As Dr Alex Bruce wrote: "Tom was always willing to assist others get a step ahead, to realise their potential and to cheer them up when life was getting them down."

Tom loved his family beyond measure, taking great pride in his wife, Dr Rose Faunce, for her work with medieval manuscripts, and in his son Blake as an emerging cricket star.

As an admirer of Dag Hammarskjöld, former U.N. Secretary General, Tom mentioned the poetic autobiographical diary Markings (Vägmärken) with its phrase "the whispering forest of books". In it, Hammarskjöld reflected that those who have much ability, talent and resources have a higher duty to serve the needy and the vulnerable. Tom strove to hold himself to this ideal and often influenced the lives of those he met. Vale Tom, friend, and mentor.

[1](2007) *Who Owns Our Health?Medical Professionalism, Law and Leadership Beyond the Market State*, (UNSW Press, 2007).
[2](Edward Elgar, 2012).
[3]*The Conversation*, 17 December 2012. https://theconversation.com/heres-to-hydrogen-australia-is-missing-the-potential-of-solar-fuels-10637

[4]*Energy Environ. Sci*., 2013, 6, 695-698, https://doi.org/10.1039/C3EE00063J
Energy Environ. Sci., 2013,6, 1074-1076, https://doi.org/10.1039/C3EE40534F
[5]*Interface Focus*, 2015, 5(3) 1-5, https://doi.org/10.1098/rsfs.2015.0029
[6]*Split by Sun: The Tragic History of the Sustainocene* (2018) https://doi.org/10.1142/q0148

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.

Researchers seek to answer key questions relating to risk, including - 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?

Research highlights

- Dr Hedda Ransan-Cooper spoke at two ANU webinars to share her studies of householder perspectives on community batteries. She was also a co-author of the paper 'Frustration, confusion and excitement: Mixed emotional responses to new household solar-battery systems in Australia', in *Energy Research & Social Science.*

- Dr Rebecca Colvin published her study of social identity, political conflict and the 'Stop Adani Convoy' in *Energy Research & Social Science*, and also *The Conversation*.

- Dr Colvin's paper in *Energy Research & Social Science* was featured in *Nature Energy* as a research highlight (Richler, J. 2020. Social identity shapes debates. *Nature Energy* 5, 277-277).

- Dr Ransan-Cooper submitted her report, Stakeholder views on the potential role of community scale storage in Australia, to ARENA's Community Models for Deploying and Operating Distributed Energy Resources project in June 2020.

- Dr Ransan-Cooper led a social research project on Engaging the Broome community on a proposed community battery project for Horizon Power.

- Professor Sara Bice facilitated an international panel on Impact Assessment for Belt and Road Initiative Projects, hosted by the International Association for Impact Assessment (IAIA) in partnership with ANU Crawford School and Tsinghua University. The symposium explored how environmental, social, health and other forms of impact assessment can mitigate negative impacts and improve societal benefits of China's US$1trillion infrastructure program, incorporating renewable energy investments.

- Dr Ransan-Cooper co-facilitated a workshop for social science researchers and practitioners from government and industry on the decentralised energy transition. The Chatham House rules workshop featured presentations and conversations about the social and policy challenges in the transition to a decentralised grid.

Cluster Members:

Convenor, Professor Sara Bice
Dr Rebecca Colvin
Professor Katherine Daniell
Associate Professor Alistair Greig
Associate Professor Llewelyn Hughes
Dr Lily O'Neil
Dr Rebecca Pearse
Professor Israr Qureshi
Dr Digby Race
Dr Hedda Ransan-Cooper
Mr Hugo Temby

Cluster member Dr Rebecca Colvin studied the Stop Adani movement and social identity. Photo: John Englart/Flickr

New energy VOICEs

The Battery Storage and Grid Integration Program in 2020 partnered with the Energy and Water Ombudsman of Victoria and the Victorian Department of Environment, Land, Water and Planning on the New energy VOICEs (Victorian Ombudsman's Investigation of Consumer Experiences) project led by Hedda Ransan-Cooper and Hugo Temby.

As part of a review of the energy consumer protection framework in Victoria, the VOICEs project documents the experiences of Australian households in engaging with a diverse range of new energy technologies, ranging from solar, batteries and electric vehicles through to microgrids, virtual power plants and peer-to-peer trading. The research is intended to lead to a better understanding of the benefits and risks of these emerging technologies, and contribute to improved outcomes for new energy consumers into the future.

Since June 2020, there have been more than 40 online interviews and focus groups covering more than 60 people and seven technologies. The report is due for release in 2021.

Energy Storage and Recovery

Short-term energy storage is becoming increasingly important to smooth out peaks of high energy demand and low energy supply. This research cluster comprises of three main themes: material chemistry research, research into pumped hydro energy storage, and fuel cell research.

Materials chemistry research
Materials chemistry research for energy conversion and storage is carried out at the Research School of Chemistry, where Professor Yun Liu has achieved a major research breakthroughs in the development of new materials for solid-state energy storage, explosive energy conversion, and liquid hydrogen storage. The materials have practical applications in renewable energy storage, electric vehicles, and defence and space technlogies.

Pumped hydro energy storage
A substantial new ANU energy research program led by Professor Andrew Blakers and Associate Professor Matthew Stocks investigated off-river Pumped Hydro Energy Storage (PHES) as a way of stabilising a 50-100% renewables contribution to the electricity system. While much attention has been on battery storage, PHES actually constitutes 99% of all existing energy storage around the world, primarily using conventional hydro-electric dams, because it is cheap compared with alternatives such as batteries.

Global pumped hydro atlas
A team led by Associate Professor Matthew Stocks and Professor Andrew Blakers in 2020 published an interactive atlas of around 616,000 potentially feasible PHES sites with storage potential of about 23 million Gigawatt-hours (GWh). This is about 100 times greater than required to support a 100% global renewable electricity system. The researchers' atlas, created using geographic information system (GIS) analysis, shows most regions of the world have large numbers of potential sites nearby.

Fuel cell research
This focuses on the development of new plasma processing techniques to fabricate fuel cell components and on the electrical testing of fuel cell assemblies. Research areas include electrode development using platinum coated carbon nano-tubes and testing of an integrated manufacturing system.

Energy nanomaterials
This research is focused on the liquid-state processing of electroceramics for energy applications. This group creates novel nanostructured ceramics with high functionality for high surface areas and quantum confinement effects.

Solar thermal energy storage
Energy storage technologies based on sensible, latent and chemical reaction heat are being developed by Professor Wojciech Lipinski's team for low- and high-temperature solar energy applications. These include high-temperature metal-oxide, carbonate, ammonia and sodium-based energy storage systems as well as clath rate hydrate systems for low-temperature energy storage.

Cluster Members:

Convenor, Professor Yun Liu
Dr Charles-Alexis Asselineau
Professor Amanda Barnard
Professor Nick Birbilis
Professor Lachlan Blackhall
Professor Andrew Blakers
Professor Rod Boswell
Dr Annie Colebatch
Associate Professor Joe Coventry
Dr Evan Franklin
Associate Professor Alexey Glushenkov
Professor Wojciech Lipinski
Dr Adrian Lowe
Dr Bin Lu
Associate Professor John Pye
Dr Ali Shirazi
Dr Igor Skryabin
Professor Sean Smith
Associate Professor Matthew Stocks
Dr Stephen Tims
Dr Juan Felipe Torres Alvarez
Associate Professor Takuya Tsuzuki
Dr Mahesh Brahmadesham Venkataraman
Professor Raymond Withers
Dr Zongyou Yin

Battery Materials and Energy Storage Lab (Battery Lab)

This national facility hosted at the ANU Research School of Chemistry opened in 2020. Led by Associate Director Alexey Glushenkov, Fellow and Research Leader at the Battery Storage and Grid Integration Program, the Battery Lab is enabling research into new battery storage technologies including the characterisation, development and performance testing of battery materials, electrolytes and devices.

Projects with international partners include research into sodium-ion and potassium-ion batteries, dual-ion batteries and hybrid energy storage (lithium-ion capacitors and related devices). Industry can use the lab to perform comparative assessments of the electrochemical performance and quality of electrode materials versus state-of-the-art commercially available standards. In November 2020 researchers at the Battery Laboratory, and colleagues, were awarded an Australian Research Council Discovery Grant valued at $420,000 for a project on dual-ion electrochemical systems.

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 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 has also presented at the World Bank in Washington DC about 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. 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
Professor Katherine Daniell
Dr Thang Do
Professor Stephen Dovers
Dr Barry Newell
Professor James Pittock
Dr Paul Wyroll

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 to allow cleaner alternatives, such as gas, to displace coal-fired electricity.

The Department of Nuclear Physics, ANU Research School of Physics, hosts the largest ion accelerator in Australia. The high energies provided by the 14UD accelerator allow Accelerator Mass Spectroscopy (AMS) measurements of the isotope ^{36}Cl at a sensitivity that is unparalleled around the globe. Measurements of ^{36}Cl 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 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 CO_2 emissions.

Cosmic rays initiate nuclear reactions in the atmosphere to continuously produce trace quantities of the radioactive isotope ^{36}Cl. The atmosphere also contains stable chlorine isotopes derived from sea spray and re-mobilised terrestrial salts. This results in a characteristic ^{36}Cl/Cl ratio for a given location, and rain water that enters the groundwater system is thus labelled by the ^{36}Cl/Cl ratio. Radioactive decay of ^{36}Cl 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 ^{36}Cl 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
Associate Professor Paul Burke
Professor Stephen Howes
Professor Frank Jotzo
Dr Arianto Patunru
Dr Digby Race
Associate Professor Budy P Resosudarmo
Professor David Stern

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 ^{36}Cl (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 ^{36}Cl content using AMS. The first appearance and subsequent time development of the ^{36}Cl signal provides information on the recoverable reserves, well-to-well 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, 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 CO_2 emissions. Much of the science and technology in this area is in common with that required for geologic storage of CO_2 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. The ANU has two prestigious ITER Science Fellows, Prof Matthew Hole and Em/Prof John Howard.

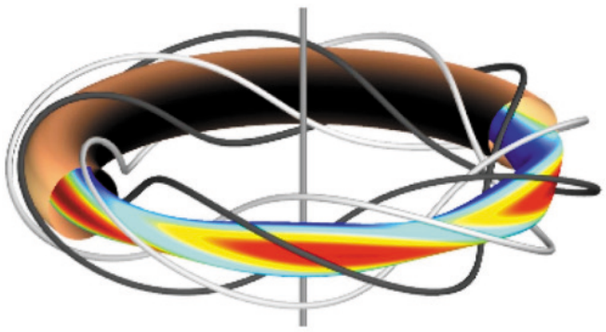
Two Schools of the ANU have fusion research activity: Mathematical Sciences Institute and the Research School of Physics. There is significant international collaboration in both schools, spanning the ITER international project, the W7-X superconducting stellarator (Germany), the KSTAR superconducting 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).

In 2020 the ANU launched an ITER-aligned research training scheme to attract the best research students. The scheme comprises a scholarship, special topics course "The Science of Toroidal Magnetic Confinement" to bring students to the forefront of the field. Travel support is available for ANU students to attend training at ITER or an ITER-relevant lab.

Mathematical Sciences Institute
This Institute hosts the hosts the Plasma Theory and Modelling Group, who develop theory and models describing high performance toroidally confined burning plasmas as well as stellarators. Fields of research include equilibrium physics, wave-particle physics and MHD stability, Bayesian inference from complex fusion data sets, and toroidal magnetic confinement experiments. The group is embedded in a research environment that includes collaboration with computational mathematics, astrophysics, and computer science research.

In 2020 several milestone research publications were generated as part of a collaboration with a prestigious Simons Foundation grant "Hidden Symmetries and Fusion Energy". Collaborator Dr Stuart Hudson, formerly of the ANU but now Deputy Head of Theoretical Physics at Princeton Plasma Physics Laboratory published the free-boundary Stepped Pressure Equilibrium code (Hudson et al, 2020) which enables a sophisticated Magnetohdrodynamics model developed by the ANU to model magnetic islands and field line chaos that exists in stellarators and real tokamaks. The free boundary version means new experiments, such as the $1bn W7-X stellarator in Germany can now be more accurately modelled.

Dr Zhisong Qu of MSI implemented a new radial basis function technique (Qu et al, 2020) based on the so-called Zernike polynomial representation, which speeds up the SPEC (Stepped Pressure Equilibrium Code) by up to a factor of 1,000. The result is important as it enables SPEC to be used in a stellarator optimisation code to design a new stellarator.



Cluster Members:

Convenor, Associate Professor Matthew Hole
Emeritus Associate Professor Boyd Blackwell
Associate Professor Cormac Corr
Emeritus Professor Bob Dewar
Professor Lilia Ferrario
Emeritus Professor John Howard
Professor Patrick Kluth
Dr Zhisong Qu
Associate Professor Stephen Tims

Figure 1: Free Boundary SPEC (Stepped Pressure Equilibrium Code). Shown is the computational boundary used in SPEC (outer surface) and the magnitude of the magnetic field on an inner surface

Research School of Physics
The School performs research in plasma-material interactions and the development of advanced remote sensing systems. The School houses two linear magnetic confinement experiments, MAGPIE I prototype device (MAGnetised Plasma Interaction Experiment) and the higher-powered MAGPIEII. Both experiments help maintain a frontline Australian research capability in fusion and plasma physics, nanotechnology, material science, and atomic and molecular physics.

Highly prized port space on ITER has been allocated for a novel optical Doppler imaging system conceived and developed by Em Prof Howard and his group at the ANU. These systems are presently installed on many frontline fusion devices around the world. In collaboration with an engineering team at ANSTO, the ITER boundary imaging system successfully concluded Conceptual Design Review in March 2019 and is now preparing for next stage review towards the end of 2021.

In 2020 the plasma-material interaction group received funding from the ARC for a Discovery Project on "Understanding helium induced nanostructure formation". This project addresses the interaction dynamics of high-flux helium particles with materials that drives surface nanowire growth and is important to the development of nuclear reactor materials. It includes a formal Implementing Agreement with the ITER Organization and collaboration with Nagoya University in Japan.

Hydrogen Economy

Hydrogen has the potential to provide the missing link between renewable energy - such as wind and solar power - and industrial energy users that have yet to find a viable alternative to fossil fuels. Additionally, zero-carbon hydrogen could be a key energy vector, allowing renewable energy to be stored and transported around the world.

The broad portfolio of hydrogen research at ANU is unique in Australia. It spans the hydrogen value chain, including technological expertise in generation and storage, as well as social license issues, governance, and economics.

Hydrogen generation

ANU researchers are developing several different emerging technologies which have the potential to drastically reduce the cost of producing hydrogen.

Advances in electrocatalysts are needed to increase the efficiency of electrolysis. Research School of Chemistry (RSC) scholars are investigating bio-mimetic electrodes for water splitting that are highly efficient. At the School of Engineering and RSC, new types of catalysts based on low-cost, metal-oxide materials are being studied. The next steps are to develop prototypes for mid-scale H_2 generation by photo- and electrochemical water splitting.

Concentrated solar thermal systems can provide the heat needed to split water with redox processes, without the need for fossil fuels. The Solar Thermal Group is developing high-temperature hydrogen generation technologies using concentrated solar energy. Photo-electrochemical (PEC) routes could allow hydrogen generation directly from sunlight, removing the need for electricity inputs. This approach is being developed by researchers across the ANU for high-efficiency solar hydrogen generation across four areas.

Storage transportation and usage

ANU researchers are investigating safer, cheaper, and more effective ways to store and transport hydrogen.

The Functional Materials Research Group (RSC), are developing liquid-state H_2 storage and conversion based on liquid organic hydrogen storage materials. This work could lead to safe, cheap, environment-friendly and scalable hydrogen storage technology at ambient temperature and pressure.

Hydrogen may also be stored and transported using ammonia as a vector. The Solar Thermal Group has significant expertise in ammonia storage from over two decades' experience developing a solar thermochemical energy storage system based on the reversible ammonia reaction.

Techno economic, governance and regulation analysis

Researchers and industry partners are developing techno-economic decision support tools for cross-validation and identification of the most feasible supply chain routes for local H_2 market and export.

Cluster Members:

Convenor, Dr Igor Skryabin
Dr Zainul Abdin
Dr Emma Aisbett
Professor Amanda Barnard
Dr Fiona Beck
Professor Nick Birbilis
Associate Professor Paul Burke
Professor Kylie Catchpole
Dr Hongjun Chen
Dr Wenting Cheng
Dr Annie Colebatch
Associate Professor Joe Coventry
Dr Reza Fazeli
Dr Jorrit Gosens
Associate Professor Llewelyn Hughes
Professor Chennupati Jagadish
Professor Frank Jotzo
Dr Siva Karuturi
Professor Wojciech Lipinski
Professor Yun Liu
Professor Warwick McKibbin
Associate Professor Ron Pace
Dr James Prest
Dr Robin Purchase
Associate Professor John Pye
Dr Alireza Rahbari
Professor Sean Smith
Professor David Stern
Associate Professor Matthew Stocks
Professor Robert Stranger
Professor H. Hoe Tan
Dr Juan Felipe Torres Alvarez
Professor Antonio Tricoli
Dr George Tsekouras
Associate Professor Takuya Tsuzuki
Dr Mahesh Brahmadesham Venkataraman
Dr Zongyou Yin

Australia-Italy research workshop

Researchers from the ANU Energy Change Institute (ECI) and the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) in December 2020 held their first joint workshop which explored their expertise in hydrogen and renewable fuels, and created foundations for future collaborations in 2021.

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 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. Recent work has assessed the presence of radioisotopes in bush foods near uranium mine sites.

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 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.

Staff have recently contributed book chapters on nuclear energy, in one case focused on achieving a low-carbon economy, in the other, on fundamentals of nuclear fission for a nuclear engineering encyclopedia.

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

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 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 College of Engineering & Computer Science 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.

Research highlights

Nanomaterials

In 2020, Professor Antonio Tricoli and his colleagues published several studies related to renewable energy applications. One study investigated the impact of morphology on the performance ß-Bi_2O_3 for CO_2 reduction reactions by imparting a fractal nanostructure. The research was published in *Advanced Functional Materials*.

The team also investigated the integration of the low-cost earth-abundant catalysts and perovskite solar cells for efficient and stable overall solar water splitting. Their paper, published in *Advanced Functional Materials*, found that encapsulating certain solar cells with CoP and FeNi(OH)x catalysts into a monolithic device, an unbiased self-powered water splitting with a solar to hydrogen efficiency of 8.54% can be achieved. Moreover, the monolithic device demonstrates continuous stable operation for over 13 hours while immersed in aqueous electrolyte.

Continuing their studies of the application of Metal Organic Frameworks (MOF) for energy storage, Prof Tricoli and his colleagues investigated the electrical conductivity and cycling stability of sulfur cathodes in high energy density Li-S batteries. They developed a facile approach for the engineering of Janus double-sided conductive/insulating microporous ion-sieving membranes that significantly enhance recharge efficiency and long-term stability of Li-S batteries. The conductive side is made of closely packed multilayers of high-aspect-ratio MOF/graphene nanosheets, while the insulating side consists of a standard polypropylene separate. The study was published in *ACS Nano*.

CO_2

Associate Professor Zongyou Yin and Prof Sean C Smith published a research article in *ACS Nano* that sought to construct efficient catalysts and to understand the underlying mechanism for carbon dioxide (CO_2) conversion. In this study, atomically dispersed indium (In–N–C) was developed as an efficient catalyst for CO_2-to-formate electrochemical conversion.

Assoc Prof Zongyou Yin and his collaborators published another paper with Haitao Zhao and Haibo Guo that developed an innovative framework which integrates data intensive rational design and experimental controllable synthesis to develop and customize crystallographic facets and facet junctions. They introduced the role of machine learning in the construction of the relationship between facets and surface energy. Their research was published in *Small*.

Cluster Members:

Convenor, Associate Professor Zongyou Yin
Dr Zainul Abdin
Dr Hongjun Chen
Associate Professor Michael Djordjevic
Professor Graham Farquhar
Associate Professor Colin Jackson
Professor Wojciech Lipinski
Dr Dean Price
Associate Professor John Pye
Dr Alireza Rahbari
Professor Antonio Tricoli

In 2019 Assoc Prof Yin and Dr Guohua Jia (Curtin University) developed a scalable stacking-hinderable strategy that provides a way to develop methanol-storable solar H2 fuel with chemical rebonding using a single-layer photocatalyst. Their work was published by *Advanced Materials*.

Solar fuels

Associate Professor John Pye's team have developed a novel strategy to produce solar fuels from supercritical water gasification of algae. Entitled Impacts of low-cost hydrogen on reformer configurations, their work was published in *Applied Energy*.

Smart Grid

The electricity grid of the future is rapidly taking shape. Ultimately, it 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. Achieving this 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.

Research highlight

The Optimal Distributed Energy Resources Scheduling for Frequency Stability project, funded by the Australian Renewable Energy Agency, aims to develop optimisation tools to enable the provision of frequency response services by network-aware DER (Distributed Energy Resources).

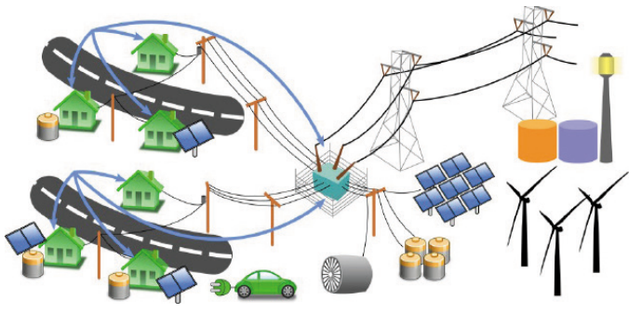
Research papers

Dr José Iria and ANU colleagues Paul Scott and Ahmad Attarha investigated the network-secure participation of aggregators of prosumers in the electricity markets. Their paper, published in *Energy*, found that it is vital to coordinate the market participation of aggregators with distribution system operators in order to avoid network violations.

Dr Iria, together with researchers and engineers from INESC TEC (Portugal) and ITU (Turkey), developed a gamification platform to increase energy efficiency in office buildings through behaviour change. The trial results demonstrated that the gamification platform contributed to the reduction of 20% of the electricity consumption of an office building in Portugal. Their paper, A gamification platform to foster energy efficiency in office buildings, was published in *Energy and Buildings*.

Dr Ratnam and Dr Chathurika Mediwaththe and co-authors proposed a decentralized control scheme called `DECSaT' for charge scheduling of EVs with the objective of tracking an arbitrary power profile while accounting for heterogeneity in EV charging specifications and also uncertainty in EV arrival times. The scheme is applicable for charging EVs at both variable rates and discrete rates, making it suitable for practical operation. Their paper was published in the IEEE Power & Energy Society Innovative Smart Grid Technologies Conference.

Dr Elizabeth Ratnam, Dr Sid Chau and co-authors proposed an energy sharing approach among customers to supply load after a wide-spread and sustained power outage, leveraging rooftop solar photovoltaic (PV) generation. Their paper was published in the Proceedings of the Eleventh ACM International Conference on Future Energy Systems.



Cluster Members:

Convenor, Dr Sid Chau
Dr Zainul Abdin
Professor Lachlan Blackhall
Dr Jamie Bright
Dr Nicholas Engerer
Dr Evan Franklin
Dr Dan Gordon
Dr Hassan Hijazi
Dr José Iria
Dr Chathurika Mediwaththe
Associate Professor John Pye
Dr Elizabeth Ratnam
Dr Paul Scott
Dr Marnie Shaw
Dr Igor Skryabin
Dr Bjorn Sturmberg
Professor Kerry Taylor
Mr Hugo Temby
Professor Sylvie Thiebaux

Dr Ratnam, Dr Marnie Shaw, Dr Mediwaththe and co-authors reviewed the literature on EV charging algorithms and identifed three control architectures for coordinated EV charging. Their study was published in *IEEE Transactions on Intelligent Transportation Systems*.

Dr Ratnam and co-authors at the University of California Berkeley proposed an innovative framework termed phasor-based control to facilitate arbitrarily high penetration levels of heterogeneous and intermittent distributed energy resources (DER) on the electric grid. A key innovation is the use of synchronized, high-precision voltage phasor measurements that allow stating control objectives in grid-specific rather than resource-specific terms. Their study was published in *Energies*.

Dr Ratnam and colleagues also studied a Phasor-Based Adaptive Control of a Test-Feeder Distribution Network. Their paper was published by *IEEE Control Systems Magazine*.

A study on Local Phasor-Based Control of DER Inverters for Voltage Regulation on Distribution Feeders examined how to improve voltage regulation and other objectives. Study co-authors included Dr Ratnam. The paper was published by the *IEEE Green Technologies Conference*.

Australian National University

Battery Storage and Grid Integration Program

An initiative of The Australian National University

Battery Storage and Grid Integration Program (BSGIP) research expands significantly in 2020

In 2020 BSGIP members researched topics including how to expand the role of electric vehicles in stabilising the electricity grid, how to implement medium-scale community batteries, and how to unlock more hosting capacity through the orchestration of smart software. BSGIP is an initiative funded by the ACT Government and created by the ECI in 2018. Members' work also involves the Energy Storage and Recovery and Energy Sociology and Risk research clusters.

Realising Electric Vehicles-to-grid Services
2020 saw the commencement of the Realising Electric Vehicles-to-grid Services (REVS) project. A two-year $6.3 million multi-partnered, cross-sector project covering the whole electricity and transport supply chains. The project, an Australian first, aims to demonstrate at scale vehicle-to-grid services. 50 ACT Government vehicles and one Actew AGL vehicle will take part in the fleet demonstration, coupled with social, technical and economic research, led by Dr Bjorn Sturmberg.

Evolve - smart software for the orchestration of 21st century electricity systems
The $13 million ARENA-funded evolve project will demonstrate cost-effective ways to increase network hosting capacity through the orchestration and co-ordination of smart software rather than building more poles and wires. The network capacity unlocked by the project will allow customers to access new opportunities to generate, store, share and trade their energy, while maintaining safe network limits. The project involves leading energy distribution companies, aggregators, tech start-ups, and the Federal and NSW governments.

Community-scale batteries
Community- or suburb-scale batteries are an emerging class of battery that complements household and utility-scale batteries. They are connected to the distribution network and can provide stored energy for up to several hundred homes. Unlike residential batteries, community batteries can potentially unlock the value of battery storage to all energy users, including vulnerable customers and customers who rent.

BSGIP's research has shown that community batteries can deliver five essential benefits including improving the fairness of the energy system, and bolstering local resilience, including socially, economically, and electrically.

In 2020 BSGIP researchers conducted three targeted projects on community-scale batteries in the ACT and Western Australia, two of which are led by Dr Marnie Shaw, and one led by Dr Hedda Ransan-Cooper.

BSGIP-Neoen partnership
In September BSGIP announced it will partner with Neoen Australia, the renewable energy company that owns the Hornsdale Power Reserve in South Australia. The three-year collaboration will see the development of methods for better managing large-scale battery storage and renewable energy generating assets such as wind or solar farms. BSGIP will develop methods for forecasting market prices and for forecasting extreme events affecting the power grid or power generation resulting in severe and immediate impact on the power market.

My Energy Marketplace
BSGIP partnered with Wattwatchers on the My Energy Marketplace (MEM) project, a unique data platform designed to give customers greater control over their energy use. The project involves the Australia-wide deployment of smart energy devices in 5,000 homes and small businesses, as well as 250 schools, to allow energy data to be monitored in real time. Information will be visualised in a range of apps that track energy generation, distribution, and consumption. The rich source of data will form the basis of research led by Dr Marnie Shaw. The data will allow more visibility to the low voltage network enabling a better understanding of energy use patterns so researchers can devise ways to optimise the charging of batteries and improve the use of smart devices.

Distributed Energy Resources Laboratory (DER Lab)
This new facility replicates the electricity network and enables safe testing under controlled conditions. It will test new technologies such as monitoring and communication devices, smart controllers, aggregation (e.g. Virtual Power Plant) and market participation software and other innovative new products under development, in a multi-platform environment.

The DER Lab will be a world-class, open-access facility for third party hardware/software developers, universities, and network and market operators. Funded by the ACT Government's Priority Investment Program, partners include ITP Renewables, evoenergy and UNSW Canberra. Located at ANU, the facility will open in 2021.

Solar Photovoltaics

Solar photovoltaics (PV) and wind energy constitute two thirds of global annual net generation capacity additions, and effectively 100 per cent in Australia. Australia is installing 6-7 Gigawatts of new solar PV and wind each year worth a combined $8 billion per year. This is the world's fastest per capita rate, and is four times faster per capita than the USA, Europe, Japan or China.

The solar cell research group was founded in 1991 and comprises 65 research and support staff and PhD students in the Research School of Electrical, Energy and Materials Engineering. Its sophisticated laboratory will receive a $6 million upgrade in 2021. Members' work includes characterisation, new materials, silicon solar cells, perovskite solar cells, tandem solar cells, accelerated life testing, industry engagement and integration of high levels of renewable energy into grids.

Characterisation
Innovation in science and technology requires the support of measurements and characterization. This is critical for any level of research – from the investigation of fundamental properties of materials, operating principles of solar cells, to the development of high efficiency solar cells and modules.

ANU solar researchers have demonstrated best-in-class efficiencies of 27.7% and 22.5%, respectively, for two different types of perovskite 'tandem' solar cells that combine the advantages of silicon and perovskite technologies.

They have also developed new imaging techniques to capture electrical and optical parameters of finished solar cells including series resistance, optical bandgap, luminescence and absorptivity. The researchers are working to uncover fundamental properties of light-matter interactions in new solar materials and devices under various conditions, based on which they aim to develop new advanced characterisation techniques for next-generation solar cells.

Silicon solar cells
Crystalline silicon solar cells have the largest solar market share, over 90% of global PV revenue. The technology in c-Si PV is continually improving towards higher efficiency, lower cost, and improved reliability. ANU solar researchers are major contributors in this various fields of research and are among leaders in the field of c-Si material defect analysis, surface passivation technologies, passivated contact technologies, device design and 3D device simulation. The world-class excellence in each research area has insofar culminated in the demonstration of highly efficient c-Si cells fabricated at ANU, achieving 25.0% Interdigitated Back Contact (IBC) cells, 24.7% efficient cells implementing passivating contact technology, and 23.2% bifacial solar cells with a near ideal bifaciality of 98%.

Cluster Members:

Convenor:
Professor Andrew Blakers
Mr Stephane Armand
Dr Fiona Beck
Professor Kylie Catchpole
Dr Marco Ernst
Dr Kean Chern Fong
Mr Liam Hayes
Dr Teng Kho
Mr Chris Jones
Dr Wensheng Liang
Dr Bin Lu
Professor Daniel McDonald
Dr Hieu Nguyen
Dr Azul Mayon
Dr Yiliang Lu
Dr The Duong
Dr Arafat Mahmud
Dr Heping Shen
Dr Jun Peng
Ms Anna Nadolny
Dr Parvathala Narangari
Associate Professor Matthew Stocks
Dr Sachine Surve
Dr Jingnan Tong
Dr Daniel Walter
Associate Professor Klaus Weber
Associate Professor Thomas White

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. In a major publication, they demonstrated best-in-class efficiencies of 27.7% and 22.5%, respectively, for two different types of perovskite '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.

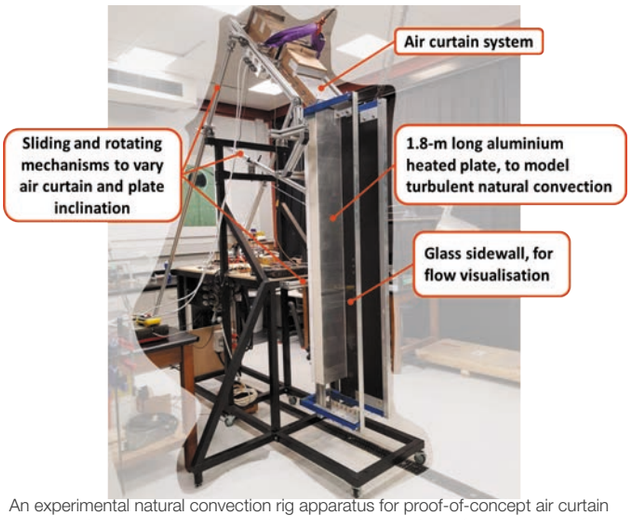
Integration of variable renewables
Electricity from solar PV and wind is now cheaper than from new-build fossil fuel power stations, and will soon fall below the cost of electricity from most existing coal power stations. Support from pumped hydro energy storage, batteries and strengthened interstate power lines facilitates a highly reliable 100% renewable energy grid. A global atlas of 616,000 off-river pumped hydro sites was published and is being used by many people around to world (http://re100.eng.anu.edu.au/global/index.php).

Solar Thermal

The Solar Thermal Group, with support from the Australian Renewable Energy Agency (ARENA), Australian Research Council (ARC), ANU Grand Challenge Program and several commercial partners, contributes to a wide range of applied and fundamental research with relevance to electricity production using concentrating solar power (CSP), and applications of solar thermal technology to industrial processing, fuel production, and capture of carbon dioxide for reuse or geosequestration.

The group has over 40 years of history and operates the world's largest CSP dish (the 500 m² SG4 Big Dish) as well as a new 45 kWe high-flux solar simulator and several other smaller pieces of high-temperature lab-scale apparatus. Together, these facilities and our associated analytical and computational capabilities make the group well-placed 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 comprises more than 30 members under the leadership of Professor Wojciech Lipinski, including nine academics, one research officer, three adjuncts and more than 20 higher-degree research students.



An experimental natural convection rig apparatus for proof-of-concept air curtain experiments, aimed at reducing natural convection heat loss from heated surfaces. It's used in the Geophysical Fluid Dynamics Lab in the Research School of Earth Sciences.

Research highlights

- A fully commissioned sodium heat transfer laboratory, to investigate the performance of sodium as a working fluid within high-temperature CSP systems.
- An experimental study of amine-infused hydrogel for CO_2 capture.

ANU Solar Thermal Big Dish.

Cluster Members:

Convenor, Associate Professor John Pye
Dr Charles-Alexis Asselineau
Associate Professor Joe Coventry
Dr Peter Kreider
Dr Apurv Kumar
Professor Wojciech Lipinski
Dr Adrian Lowe
Dr Alireza Rahbari
Dr Juan Felipe Torres Alvarez
Professor Antonio Tricoli
Dr Mahesh Brahmadesham Venkataraman
Dr Xiaolin (Shannon) Wang
Adjunct Professor Alan Weimer

- Proof-of-concept experiments & simulations for reduction of turbulent natural convection from heated surfaces using planar air jet. Air jets are proposed as a strategy to improve the efficiency of large-scale solar collectors.
- An experimental study of gas hydrate kinetic promoters' effects for efficient CO_2 capture.
- An experimental and modelling study of packed-bed cold thermal storage with PCM capsules in various geometries.
- Spectroscopic characterization of participating media for use in solar thermochemistry applications.
- Numerical simulations of gas—particle flows using the multiphase computational simulations.
- Design of a high-temperature full-scale sodium receiver in support of the Liquids Pathway in the US Department of Energy 'Gen3 CSP' program, in a project led by the National Renewable Energy Laboratories (NREL).
- System-level modelling of particle-based CSP systems for the major US DOE 'G3P3' project led by Sandia National Laboratories, which was selected to proceed to a large-scale trial in March 2021.

Many of these topics were featured in a major review paper authored by Prof Wojciech Lipinski and other group members titled 'Progress in heat transfer research for high-temperature solar thermal applications' in *Applied Thermal Engineering.*

Sustainable Transport

Greenhouse gas emissions due to transport are projected to comprise an increasing fraction of Australia's emission profile as the electricity sector decarbonises, increasing its importance to achieve carbon reductions both domestically and internationally.

Sustainable Transport Policy

Research within the Crawford School of Public Policy involves examining the policy settings required to achieve a sustainable transport sector.

In 2019, Paul Burke and a colleague from Kwansei Gakuin University in Japan published a paper on the effects of an emissions-based restriction on vehicle registrations in Japan. The restriction was only introduced in some municipalities. The research found that the intervention led to a reduction in the mean ambient concentration of nitrogen dioxide (NO_2) of 3–6% on average in these municipalities over the subsequent years. The research was published in *Contemporary Economic Policy* and is of relevance to other jurisdictions that are considering steps to improve urban air quality.

In 2019 Paul Burke published a paper with Rohan Best that sought to understand the underlying reasons for an uptick in road deaths in New Zealand. They found that a decline in fuel prices, an increase in international tourism, and factors such as a declining unemployment rate were among underlying contributors to the rising road death toll. The findings are relevant for informing the optimal timing of road safety interventions, and accord with similar findings obtained for Australia and using international data. The research was published in *New Zealand Economic Papers*.

Electric Vehicles

V2G (Vehicle-to-grid)

The Battery and Grid Integration Program are undertaking a $2.4M ARENA funded project, Realising Electric Vehicle-to-Grid Services (REVS), led by Bjorn Strumberg. REVS will examine how vehicle-to-grid (V2G) functionalities can support grid stability. Fifty ACT Government Nissan LEAF EVs and one ActewAGL Nissan LEAF EV will take part in this ground-breaking study that will allow EV batteries to provide power into the grid, almost instantaneously when needed, to avoid blackouts. The project aims to demonstrate V2G technology providing contingency frequency control ancillary services (FCAS) to the National Electricity Market, complemented with a holistic roadmap for the mass deployment of the full value stack of V2G services. This will lead to new V2G-enabled service offerings for fleets and residential customers.

Politics

Lee White from the College of Asia and the Pacific published work examining how electric vehicle (EV) acceptance varies across political ideologies. EV symbolic attributes, or the extent to which people perceive EVs to reinforce aspects of their identities, are among the strongest predictors of EV adoption intentions, and may contribute to this group difference. The primary objectives of the study were to better understand the role of social (in this case, political) identity in symbolic attribute perceptions, and how these variables work together to influence EV adoption intentions. Using an identity framework, this study advanced understanding of the psychological mechanisms that help explain differences in EV adoption intent among U.S. Democrats vs. Republicans, and offers guidance for targeted marketing efforts to enhance EV uptake.

Cluster Members:

Convenor, Associate Professor Matthew Stocks
Associate Professor Paul Burke
Professor Andrew Blakers
Associate Professor Paul Burke
Dr Sid Chau
Dr Reza Fazeli
Dr José Iria
Dr Thomas Longden
Dr Elizabeth Ratnam
Professor David Stern
Dr Bjorn Sturmberg
Mr Hugo Temby
Dr Lee White
Dr Paul Wyrwoll

100% Renewable Energy

The RE100 Group is examining the decarbonising transport through the use of renewable electricity which will result in increased electricity demand. Bin Lu led a study of a fully decarbonised electricity system is modelled together with complete electrification of heating, transport and industry in Australia leading to an 80% reduction in greenhouse gas emissions.The results show that high levels of energy reliability and affordability can be effectively achieved through a synergy of flexible energy sources; interconnection of electricity grids over large areas; response from demand-side participation; and mass energy storage.

Work has also been submitted examining similar scenario analysis for South East Asia.

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.

The Wind Energy course was developed by Windlab as part of the ACT Renewable Reverse Auctions process, in which companies that tendered to supply the ACT with renewable energy also agreed to invest in the tertiary education sector. 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. Around 30 undergraduate students completed the course in 2019 and 2020.

After four years of delivery by Windlab, the course transferred to the School of Engineering at ANU in 2020. Windlab continue to be involved in the course delivery and assessment through Dr David Osmond.

Associate Professor Matthew Stocks undertook course convening and the primary lecturing role, supported by industry guest lectures from Vestas, Energy Estate and Ecology and Heritage partners.

Around 30 students have completed the Wind Energy course in 2019 and 2020. 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.

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
Dr Rebecca Colvin
Dr Elizabeth Hanna
Associate Professor Andy Hogg
Dr Frank Mills
Dr David Osmond (affiliate, Windlab)
Dr James Prest
Dr Igor Skryabin
Dr Nathan Steggel (affiliate, Windlab)
Associate Professor Matt Stocks

Research highlights

An interview with Dr Bec Colvin about her research on social conflict about wind energy development was included in Ketan Joshi's book, *Windfall: Unlocking a fossil-free future* (New South Books, 2020).

Dr James Prest worked on several papers arising from his project on "Litigation over Renewable Energy Developments in Australia". One was presented by invitation in February 2020 to the University of Helsinki's Institute of Sustainability Science seminar on Court Review of Complex Environmental Knowledge and Impacts.

He also wrote about the ongoing civil prosecution of wind farm companies in the Federal Court by the Australian Energy Regulator for alleged breaches of the National Electricity Rules arising from the South Australian blackout of September 2016. A second article investigated the refusal of planning permission for of a wind farm proposed near Canberra based on cumulative visual impacts by the NSW Independent Planning Commission, and the subsequent reversal of that decision in a negotiated outcome in the Land and Environment Court.

ANU researchers set new solar-to-hydrogen efficiency record

Researchers at The Australian National University (ANU) have achieved a new efficiency record for hydrogen cells that can convert water into hydrogen simply using sunlight.

Lead author Dr Siva Karuturi says hydrogen has an important role to play in solving the intermittency of renewable energy sources.

“There are significant cost benefits to this solar-to-hydrogen approach as it eliminates the need for added infrastructure that’s necessary when hydrogen is produced using an electrolyser.”

Previous methods of converting water to hydrogen have had a low overall energy conversion efficiency but Dr Karuturi’s research has improved this.

“To produce hydrogen in the past, solar plants had to produce electricity which is then used to electrolyse water to produce hydrogen. This new method is more direct, making it more efficient,” he said.

The unique approach outlined in the ANU study, which was published in Advanced Energy Materials, also used inexpensive semiconductor materials and resulted in a 17.6 per cent solar-to-hydrogen efficiency.

This is nearing the efficiency of solar panels being installed on rooftops, which have an efficiency of around 20 per cent.

Dr Karuturi says that they are working towards reaching an efficiency of 20 per cent in the coming months, which will pave way for low-cost green hydrogen production.

The research team used a “tandem” light absorber structure-placing a perovskite cell on top of a specially-made Si electrode.

Co-author Dr Heping Shen, who develops perovskite cells, says with extraordinary optoelectronic properties, the perovskite materials offer great potential for low-cost, high-efficiency tandem devices with Si.

“Together with unprecedented progress in efficiency, the perovskite material has also undergone significant improvement for its stability, making it one of the most attractive candidates for the solar industry,” Dr Shen said.

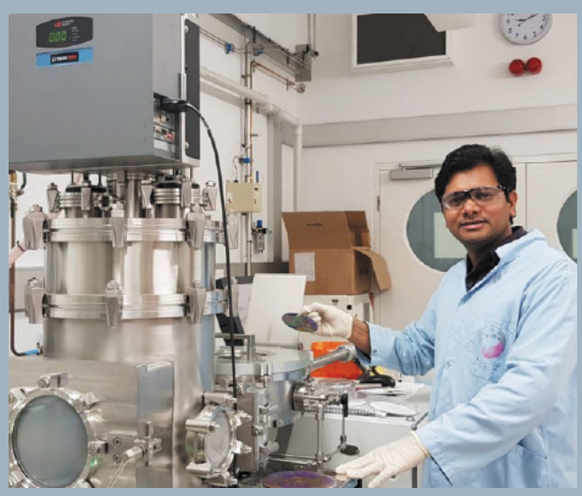
“There are significant cost benefits to this solar-to-hydrogen approach as it eliminates the need for added infrastructure that’s necessary when hydrogen is produced using an electrolyser”.

This new method makes use of noble-metal catalysts such as platinum and Dr Karuturi says that they are working to replace them with cheap materials to further reduce costs in the future.

Another major outcome for the research is that Australia will more efficiently be able to export hydrogen.

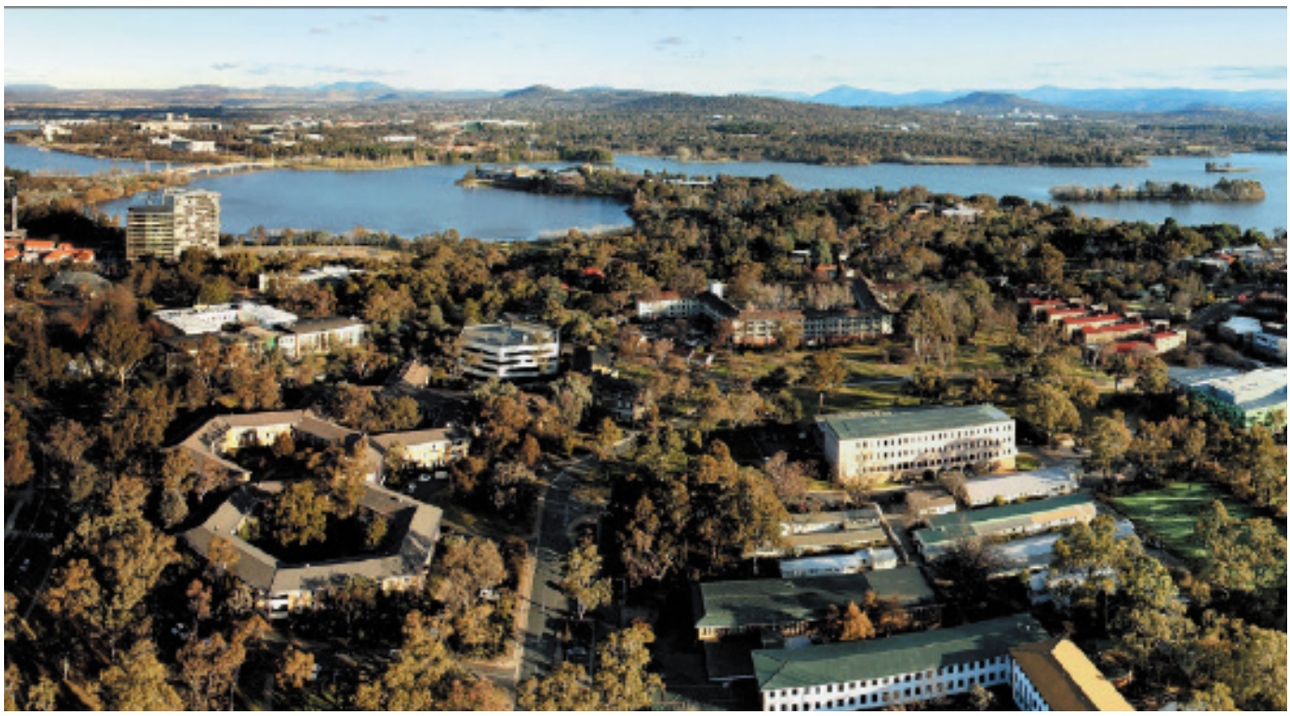
Dr Karuturi noted that in 2019 the Council of Australian Governments (COAG) Energy Council approved a national hydrogen strategy which aims to enable a hydrogen economy.

“This strategy is important to Australia and our hope is that this new, direct method of converting water to hydrogen can aid these efforts,” said Dr Karuturi.



Dr Siva Karaturi

ANU BELOW ZERO INITIATIVE



Aerial view of ANU campus.

In 2020 the University began developing a plan to reduce the national university's emissions to below net zero, and show leadership in line with the world's best practice on emissions reduction. The Below Zero Initiative, approved by the ANU Council in February 2020, builds on the University's Energy Master Plan in which the ECI played a major role. The ECI will help guide the new initiative, and Director Prof Ken Baldwin is part of its Management Group. One goal is to embed ECI members' research into the University's plan for emissions reduction below zero.

The campus' main sources of greenhouse gas emissions are gas use, followed by air travel. The biggest short-term opportunities to reduce emissions will be to transition from natural gas, energy efficiency, onsite solar PV, reducing air travel, and using electric vehicles.

The initiative comprises seven themes: leadership and targets, energy and buildings, travel, behavioural change, removing atmospheric greenhouse gases, finance, investment and purchasing, and integrating below zero operations, research and teaching.

Seven workshops were held from September to October to collate ideas from the university community and wider public. There was considerable support for demonstrating leadership on emissions reduction. These views will be reflected in the final report which will be presented to the University leadership.

The University will continue working on the initiative in 2021.

Sliver cell solar panel installation on the Anthony Low Building, ANU.

EVENTS

The ECI organised one public event in 2020 before we moved online in response to the COVID-19 pandemic. This change allowed us to reach new audiences across Australia and internationally who hadn't previously been able to attend. Our events range 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

Flagship events / meetings

ECI Open Day
17 February 2020

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.

A full house at the 2020 Energy Open Day.

ECI Annual Business Meeting
9 September 2020

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 Australian Ambassador for the Environment, Jamie Isbister, provided the keynote address, and explained what happens during international climate negoations.

2020 ANU Solar Oration
17 November 2020

Professor Mark Z Jacobson, Director of the Atmosphere Energy Program, Stanford University, explored plans for how the world could transition to electricity powered by 100% wind, water and sunlight, and the consequences of Joe Biden winning the 2020 US Presidential election.

2020 ANU Energy Update
3 December 2020

The annual ANU Energy Update webinar examined in detail the latest world energy trends from the International Energy Agency's World Energy Outlook (WEO) 2020. The main presentation, by Ian Cronshaw, a contributor to 13 WEOs, was followed by an expert panel comprising Nicola Falcon from the Australian Energy Market Operator, Professor Kylie Catchpole (ANU), Luke Menzel from the Energy Efficiency Council, and Professor Stephen Wilson from the University of Queensland. It was moderated by Professor Ken Baldwin.

ECI public lectures, seminars and symposiums

Imagining Australila with 100% Renewable Energy

A public lecture co-hosted by ANU 100% Renewable Energy research group; ANU Energy Change Institute; UNSW School of Photovoltaic and Renewable Energy Engineering; the Australian Centre for Advanced Photovoltaics; and the Energy Transition Hub, 17 February 2020.

Variable Generation, Flexible Demand: The California Experience

A public webinar hosted by ECI about how California is moving to a future of predicting variable renewable generation and determining how best to schedule demand to match it. It was delivered by Dr Fereidoon Sioshansi, President of Menlo Energy Economics,15 April 2020.

Master of Energy / Master of Climate Change webinars

Three webinars were held in 2020. The first on 26 May exlored the student experience and featured student Desy Prihardini. The second on 16 June was co-hosted by the ECI and Climate Change Institute and targeted potential students in Indonesia. The third webinar, co-hosted by ECI, College of Science, and the Climate Change Institute, was part of ANU Virtual Open Week on 24 August 2020.

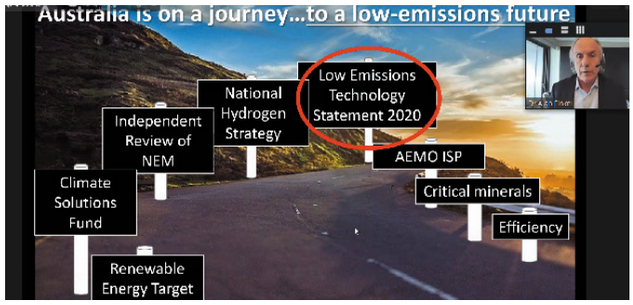
Technology Investment Roadmap public forums

The first, on 12 June, featured experts from ANU, industry, CSIRO, and members of the Department of Industry, Science, Energy and Resources team which was tasked with gathering views for the roadmap.

EVENTS

Technology Investment Roadmap public forums

The second public forum, on 8 October, featured former Australian Chief Scientist Dr Alan Finkel AO (pictured below), and followed the release of the roadmap and accompanying FIrst Low Emissions Technology Statement. The panel comprised experts from ANU, CSIRO, and the wider energy community.



Public Forum: How do we certify the amount of carbon embedded in hydrogen fuels?

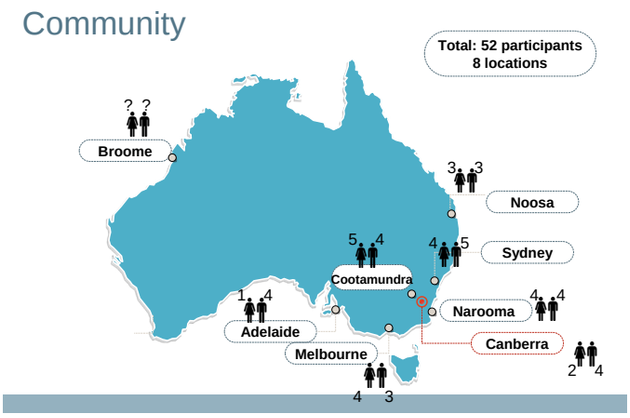
Hosted by ECI, the forum on 8 September heard the results from the Australian Government's survey on Hydrogen Certification, and gained perspectives from ANU research on hydrogen and ammonia certification, and industry. The speakers were Rebecca Thomson (Hydrogen Strategy Team, Department of Industry, Science, Energy and Resources), Dr Emma Aisbett (Associate Director (Research), ANU Energy Change Institute Grand Challenge: Zero-Carbon Energy for the Asia-Pacific), Penelope Howarth, Department of Foreign Affairs and Trade (on secondment to the Grand Challenge team), and Dr John Söderbaum of ACIL Allen Consulting.

The hydrogen certification public forum featured a presentation by Rebecca Thomson from the Australian Government's Department of Industry, Science, Resources and Energy.

Energy Conversations series 2020

Developments in community-based battery storage

Hosted by ECI, it featured Dr Marnie Shaw and Dr Hedda Ransan-Cooper, both of the Battery Storage and Grid Integration Program, who shared their research on community battery storage projects in Australia. 13 May 2020.



Locations of some of the Australian communities studied for their views about battery storage schemes. Presented at the Energy Conversations webinar on 13 May.

Carbon-neutral fuels for aerospace

Co-hosted by the ECI and ANU Institute for Space (ANU InSpace), this webinar featured experts from the ANU, ArianeGroup, Airbus, and the Australian Renewable Energy Agency (ARENA), 22 July 2020.

Public Forum: Australia, the global renewable energy pathfinder

Hosted by ECI, the forum on 24 September featured ANU academics, and a panel comprising members of the Australian Energy Market Operator (AEMO) and Clean Energy Regulator.

Renewable Fuels - World Space Week 2020

Hosted by the ANU Institute for Space on 8 October, this webinar featured a discussion on research into innovative space fuel technologies like hydrogen.

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

> **Dr Thomas Longden** wrote an analysis of the Australian Hydrogen Strategy for a policy brief series by Germany's Konrad Adenauer Stiftung.

Federal Government

> The Energy Change Institute provided a submission to the Technology Investment Roadmap discussion paper in 2020. Submissions were also provided by the ANU Climate Change Institute, the Battery Storage & Grid Integration Program, the Centre for Climate Economics and Policy, and colleagues from the College of Engineering and Computer Sciences, whose submisson emphasised Solar PV and wind generation.

> The Energy Change Institute provided a submission to the Australian Parliament's Joint Standing Committee on Trade and Investment Growth. ECI members Dr Emma Aisbett, Dr Fiona Beck, Dr Lily O'Neill, Associate Professor Matthew Stocks, Associate Professor Llewelyn Hughes and Dr John Pye also gave testimony to the inquiry on 12 August, which examined ways of diversifying Australia's Trade and Investment Profile.

> The ANU Grand Challenge: Zero-Carbon Energy for the Asia-Pacific, made submissions to the Australian Government's Review of Australia's Bilateral Investment Treaties, Hydrogen Certification Survey, and two submissions to the Draft 2020 Integrated System Plan for the National Electricity Market.

> The Battery Storage and Grid Integration Program made a submission to the Energy Security Board's Post 2025 Market Design Consulation Paper.

> Professor Andrew Blakers, Associate Professor Matthew Stocks, and Dr Bin Lu wrote papers on photovoltaics, wind and pumped hydro energy storage for the Australian Parliamentary Library's Research Paper Series, Australian electrcity options, in July 2020.

> Members of the ECI and ANU Grand Challenge: *Zero-Carbon Energy for the Asia-Pacific* held quarterly meetings with the Australian Renewable Energy Agency (ARENA) to discuss their research. Several stories about ECI members' research featured in ARENA's monthly newsletter in 2020.

> ECI members made a submission to an Australian Parliamentary inquiry into two bills about Climate Change (National Framework for Adaptation and Mitigation).

> The ECI in 2019 wrote to an inquiry into 'Jobs for the Future in Regional Areas' in which the ECI emphasised renewable energy opportunities.

> In 2019 the ECI made a submission to an inquiry into the prerequistes for nuclear energy in Australia.

State/Territory Government

> Members of the ANU Grand Challenge: *Zero-Carbon Energy for the Asia-Pacific* made a submission to the West Australian Government's Aboriginal Empowerment Strategy.

Individual contributions

ECI researchers contribute to public policy development through their individual research expertise as part of their everyday activities – particularly in the disciplines of economics, law, sociology, and policy. Among many individual achievements throughout the year, ECI researchers contributed to the following areas of public policy:

Professor Andrew Blakers provided a submission to the Australian Energy Market Operator (AEMO) Draft Systems Integration Plan, February 2020.

Energy Research Institutes Council for Australia (ERICA)

In 2020 ECI members participated in a range of events hosted by the Energy Research Institutes Council for Australia (ERICA) – a peak body representing energy research in this country, and in which ECI Director Ken Baldwin played a major role in establishing in 2017.

The ECI helped promote ERICA events, and ECI events were in turn supported and promoted by ERICA and its members.

Its members are energy institutes or centres at the University of Adelaide, ANU, Curtin University, Deakin University, University of Melbourne, Monash University, the University University of New South Wales, of Queensland, University of Sydney, University of Tasmania, University of Technology Sydney, and Victoria University.

In October, the ECI's Prof Frank Jotzo joined an ERICA webinar on COVID-19: the impacts of a global pandemic on our energy system.

ERICA co-supported the ANU Energy Update on 4 December, Prof Steven Wilson, from the Centre for Energy Futures at the University of Queensland, was a panelist.

ANU GRAND CHALLENGE:
ZERO-CARBON ENERGY FOR THE ASIA-PACIFIC

In what has been a tumultuous year for Australia and the world, the transition to a global energy future based on trade in renewable energy and embedded energy products has continued unabated, as has the work in the Grand Challenge.

Significant progress has been made by our existing industry partners to advance the interests of major renewable energy export projects. Both Sun Cable and the Asian Renewable Energy Hub (AREH) have received Major Project status from the Federal Government, and AREH has had its environmental plan approved by the WA Government for the first 15GW of its 26GW planned development. We will continue to work closely with our partners to understand their research needs and to co-design our evolving research projects.

Our engagement with government has continued to grow, synergised by the presence of our secondees from the Department of Industry, Science, Energy and Resources (DISER – David Gourlay, Chell Lyons and Alison Reeve) and from the Department of Foreign Affairs and Trade (DFAT – Penelope Howarth). Our work on hydrogen certification has grown and we have been engaged with fruitful discussions with the Australian Hydrogen Taskforce in DISER as well as the ACT Government through the ACT Renewables Hub now operated by the Smart Energy Council (SEC).

In partnership with the ACT Hub and the SEC we have been awarded a hydrogen cluster with National Energy Resources Australia. And the ANU has entered into a Strategic Research Agreement with CSIRO that explicitly includes Hydrogen Technologies among the five collaborative programs.

In 2020, the five Grand Challenge research projects:

- Renewable Energy Systems
- Hydrogen Fuels
- Renewable Energy Policy and Governance in Asia-Pacific countries
- Renewable Metal Refining
- Indigenous Engagement with Renewable Energy Industries

have continued to create new knowledge with one edited book, 27 international journal articles, 27 short articles, two Grand Challenge papers, and 21 papers under review.

In addition 61 presentations have been made at workshops, roundtables and national/international conferences.

The Grand Challenge also made 12 submissions to government inquiries, and Team members appeared 97 times in articles and interviews in a wide range of media outlets.

In 2020, Grand Challenge Fellow, Dr Thomas Longden, wrote a paper explaining for Germany's Konrad Adenauer Stiftung that explained Australia's Hydrogen Strategy.

Dr Emma Aisbett (pictured) and Prof Ken Baldwin presented to an audience of more than 50 Australian public servants in Canberra in March. Dr Aisbett discussed the Grand Challenge, while Prof Baldwin explained Australia's domestic electricity transition.

Grand Challenge team members gathered for the two-day retreat in September in-person at Kambri, and also via Zoom.

OUTREACH

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 in which ECI members have been involved.

International engagement

At least four ECI members were among the 29 participants in the KAS Energy Policy Dialogue webinar in July. Source: KAS Facebook.

ECI members including **Richard Andrews, Dr Emma Aisbett, Professor Frank Jotzo** and **Dr Thomas Longden** joined an Energy Policy Diaologue webinar in July 2020 hosted by the Konrad Adenauer Stiftung (KAS) in cooperation with the Energy Transition Hub. They discussed Hydrogen Strategies in Germany and Australia. In August 2020, **Dr Longden** wrote an Analysis of the Australian Hydrogen Strategy for KAS' Periscope policy brief series.

The **ECI** and the **Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA)** held their first joint workshop in December 2020. Held online over two days and with the support of Australia's Department of Foreign Affairs and Trade and the Embassy of Italy in Australia, researchers discussed their expertise in hydrogen and renewable fuels.

Associate Professor Llewelyn Hughes in November organised a public forum webinar with two academics at the Tokyo University to explain Japan's goal to reach net zero emissions by 2050.

ECI's Director **Professor Ken Baldwin** wrote the foreword for *'Variable Generation, Flexible Demand'* (2020), edited by Fereidoon Sioshansi. The book covered topics canvassed at the 2019 Future Electricity Market Summit which the ECI co-hosted in Sydney. Several participants in that summit, including the book's editor, also contributed to the book.

Community engagement

Professor Ken Baldwin presented at webinar hosted by the ACT Branch of Renew in March. He explained Australia's domestic energy transition, and also outlined the ANU Grand Challenge: *Zero-Carbon Energy for the Asia-Pacific* research project.

Professor Andrew Blakers addressed the Renewable Energy in the Central West community forum. He discussed the need for renewable energy zones. His expertise was also featured in two books – former Prime Minister Malcolm Turnbull's autobiography, and *Ten Journeys On A Fragile Planet*.

Dr John Pye discussed his team's research in a community webinar in October on 'Green steel and the future of the Illawarra'.

Dr Marnie Shaw served on an panel which advised federal Member for Indi, Dr Helen Haines MP's Local Power Plan community energy project.

Industry engagement

Dr Fiona Beck joined the Hydrogen Futures Workshop in Melbourne in March hosted by the Australian Academy of Technology and Engineering and Korea's NAEK.

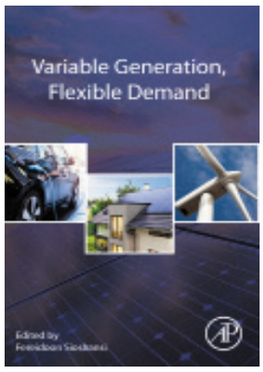
Professor Ken Baldwin spoke at the August 2020 launch of the ACT Renewables Hub initiative, a virtual entity which replaced the ACT Renewable Innovations Hub and the South East Region of Renewable Energy Excellence (SERREE). The Smart Energy Council now manages the Hub, on behalf of the ACT Government.

Dr Igor Skryabin was reappointed to the Advisory Board of the APEC (Asia-Pacific Economic Cooperation) Sustainable Energy Center (APSEC) for a further three-year term.

Professor Andrew Blakers spoke at the Renew Economy webinar, 'How efficient can big solar be?'

Professor Ken Baldwin, Dr Emma Aisbett, Research Fellow **Penelope Howarth** participated in All-Energy Australia Conference webinars in 2020.

Dr Bjorn Sturmberg spoke about his team's electric vehicle research projects at the National Roads and Traffic Expo in 2020.



Ken Baldwin wrote the foreword to *Variable Generation, Flexible Demand* (2020).

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.

Decarbonisation of energy

"Japan and South Korea commit to net zero," interview with Associate Professor Llewelyn Hughes, 31 October 2020, *ABC Radio PM.*

"Queensland teenagers lodge legal action against Adani coal mine to save Great Barrier Reef" interview with Associate Professor Paul Burke, 22 October 2020, *ABC News*.

"The big opportunities behind a zero-carbon grand challenge," interview with Dr Emma Aisbett and Dr Fiona Beck, 1 June 2020, *Create Digital*/Engineers Australia.

"Australia must declare World War Zero on carbon emissions," written by Dr Bjorn Sturmberg, 15 January 2020, *The Canberra Times*.

National energy policy

"The Green Recovery: how Australia can clean up its act on energy," interview with Professor Ken Baldwin, 5 August, *The Guardian.*

"The Green Recovery: how Australia can ditch coal without ditching jobs", interview with Professor Ken Baldwin, 27 August 2020, *The Guardian*.

"Gas a key part of government's plan to revive Australian economy", interview featuring Professor Frank Jotzo, 14 August 2020, *Radio National*.

Energy security

"The future of oil" interview with Dr Christian Downie, 25 April 2020, ABC Radio AM.

Plunging oil prices will have huge consequences, written by Dr Christian Downie, 22 April 2020, *The Straits Times* (Singapore).

Pumped hydro energy storage

"Off-river pumped hydro could provide lower costs for energy storage", written by Professor Andrew Blakers and Associate Professor Matthew Stocks, 22 May 2020, *Renew Economy*.

Solar power

Solar energy, Nepal's most sustainable resource, 1 December 2020, Professor Andrew Blakers and Sunil Prasad Lohani, *The Himalayan Times* (Kathmandu).

'Companies are made of people': Mandurah Aldi supermarket to go solar, interview with Professor Andrew Blakers, 9 September 2020, *Mandurah Mail*.

Technology leads driving cost of solar PV electricity in Australia ito just A$30/MWh, 7 May 2020, written by Professor Andrew Blakers and Associate Professor Matthew Stocks, *Renew Economy*.

Why solar energy can help Indonesia attain 100% green electricity by 2050, 22 April 2020, David Silalahi, *The Conversation*.

Dr Jennifer Hunt (pictured) and Professor Andrew Blakers were provided expert commentary about the 1970s OPEC oil crisis and solar photovolatics in the Energy Revolutions episode of the ABC-TV series The Great Disruption (2020).

Technology Investment Roadmapy

"What will win the race between renewables and fossil fuels to power the nation's energy needs," interview with Professor Frank Jotzo, 26 May 2020, ABC Radio PM.

"The 2020 Technology Investment Roadmap", interview with Professor Ken Baldwin, 22 May 2020, ABC Radio NSW Countryhour.

Transport and Energy

"Owners of electric vehicles to be paid to plug into the grid to help avoid blackouts" written by Dr Bjorn Sturmberg, 8 July 2020, *The Conversation*.

Media releases

The ANU publicises ECI research and news via media releases and other promotional avenues. Coverage by an ANU media release and social media support can have a broad reach, domestically and internationally.

Research to power up Australian solar cells
6 October 2020

The power of battery storage recharged with cash splash
15 September 2020

Australia leading the world in deployment of renewable energy
3 September 2020

New study offers roadmap for coal phase-out
28 July 2020

ANU researchers set new solar-to-hydrogen efficiency record
27 July 2020

World's largest study shows carbon pricing reduces emissions
14 July 2020

Electric vehicle fleets set to be on-call to backup the grid
8 July 2020

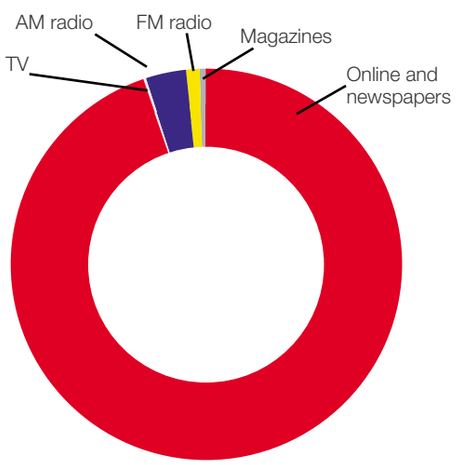
ANU-ActewAGL project to explore housing energy efficiency
7 May 2020

Health and environmental protections at risk during COVID-19
15 April 2020

New record could usher in new era for solar energy
11 March 2020

Funding boost to float Australia's hydrogen energy future
11 February 2020

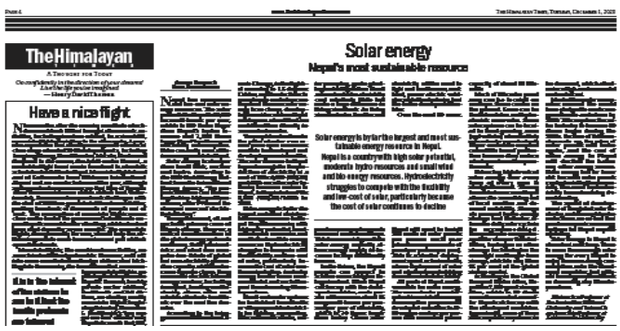
ECI Executive Media Type Breakdown – Volume



Communications

ECI Communications in 2020 focussed on activities including promoting ECI research and events and building and supporting ECI membership. We also strengthened partnerships and connections between ECI members and external stakeholders in government, industry, NGOs and the community, and promoted the Master of Energy Change degree domestically and internationally.

Our main communication channels were online events, media relations and digital communications, including ANU websites, a monthly newsletter to our database of more than 7,500 subscribers and social media. The Institute created a LinkedIn accont in May 2020, which had more than 170 followers at the end of 2020. The ECI Twitter account (@ANUEnergyChange) had 1,763 followers at the end of 2020, and 426 followers on Facebook (ANU Energy Change).


TheHimalayan

Solar energy

Nepal's most sustainable resource

Have a nice fight

Professor Andrew Blakers and Sunil Prasad Lohani (Kathmandu University) co-authored an opinion piece on Nepal's solar energy possibilities, which was published in *The Himalayan Times* (2020).

HONOURS AND AWARDS

Professor Sara Bice - Award for Teaching Excellence

Professor Sara Bice in 2020 received an ANU College of Asia and the Pacific Award for Excellence in Education. She was recognised for her innovative approach to teaching, which translates into highly engaging and workplace-relevant learning experiences for her students. The ciation said one crucial strength of Professor Bice's teaching being project and case-based learning, which puts her students front and centre. Professor Bice was also awarded the International Association for Impace Assessment Outstanding Service Award in 2020. Professor Bice is Convenor of the Energy Sociology and Risk research cluster.

Dr Bec Colvin - Award for Teaching Excellence

Dr Bec Colvin in 2020 was recognised with an ANU College of Asia and the Pacific Award for Excellence in Education. Dr Colvin received the award for the great amount of care she takes when team teaching and the leadership role she plays in supporting her tutors. Her citation said Dr Colvin has made excellent use of innovative online tools and well-designed visual summaries and dedicated a considerable amount of time to creating engaging video presentations, which entailed, among other things, arranging contributions made by guest speakers from around the world. Dr Colvin is a member of the Energy Sociology and Risk, and Wind Energy research clusters.

Dr Nick Cox - ICMRBS Founders Medal

Dr Nick Cox received the International Conference of Magnetic Resonance in Biological Systems (ICMRBS) Founders Medalin 2020. Dr. Cox was recognised for his achievement in developing and applying high-field electrong paramagnetic resonance (EPR) techniques to elucidate water splitting in oxidative photosynthesis and to the study of metal cofactors in metalloenzymes. Dr Cox is a member of the Artificial Photosynthesis research cluster.

Professor Tim Senden - 25 years' academic service

Professor Tim Senden in 2020 received a 25 Years of Service Award from The Australian National University. Professor Senden is a member of the Carbon Capture and Storage and Enhanced Oil and Gas Extraction research clusters.

Dr Igor Skryabin - APEC Sustainable Energy Center

Dr Igor Skryabin was in September 2020 reappointed to the Advisory Board of the APEC (Asia-Pacific Economic Cooperation) Sustainable Energy Center (APSEC) for another three-year term. The APSEC work program includes helping member economics to enact energy transition solutions, clean coal technology transfer, and help local communities develop energy sustainably, and be economically vibrant. Dr Skryabin is the ECI's Research and Business Development Manager, and Convenor of the Hydrogen Economy Research Cluster.

OUTLOOK

Lake George, wind turbines.

As the Energy Change Institute moves into a new era following its first 10 years of achievement, we look forward to being a part of the new Institute for Climate, Energy & Disaster Solutions (ICEDS) at ANU. As can be seen in the highlights section in this year's annual report, Energy at ANU will continue to be a 'go to' destination for energy research, education and outreach, enhanced by our relationship with our sister institutes in ICEDS.

Australia is now leading the world in the energy transition, coming from a highly carbonised starting point but transitioning per capita to renewable electricity at the fastest rate of any nation. In order to ensure that we optimise our opportunities in the energy transition, research must play a key role in this process.

The research we undertake in Energy at ANU will be an important part of the Australian Energy Transition Research Plan being developed by the Australian Council of Learned Academies.

Through our flagship program in the ANU Grand Challenge: *Zero-Carbon Energy for the Asia-Pacific*, we will also contribute to the transition of our export economy. This renewable energy export future will be coupled with – and potentially dominate – the domestic energy transition.

We look forward to working with you on these key elements of Australia's energy future.

ADVISORY BOARD MEMBERSHIP

Professor Armin Aberle - Solar Energy Research Institute of Singapore

Armin Aberle is the CEO of the Solar Energy Research Institute of Singapore (SERIS) at the National University of Singapore (NUS) and a professor in the university's Department of Electrical and Computer Engineering. His research focus is on reducing the cost of solar electricity generated with silicon solar cells, both wafer based and thin-film based. His work has covered the full spectrum from fundamental materials research to the industrial evaluation of novel PV technologies at the pilot line level, including the development of novel solar cells, their fabrication in the laboratory, their characterisation, and their computer modeling. He has published extensively and his work has a high impact on the field.

Mr Brad Archer - Chair, Climate Change Authority, Australian Government

Brad Archer has extensive experience working on climate change, renewable energy and energy market issues. He joined the Climate Change Authority in November 2018. Previously, he was head of the International Climate Change and Energy Innovation Division in the Australian Government Department of the Environment and Energy, where his responsibilities included advising on clean energy innovation, Australia's greenhouse gas inventory, and international climate change policy. Brad has been working on climate change policies for the Australian Government since early 2011. Prior to this he worked on a range of issues in the Treasury, which he joined in 1991. Brad has qualifications in economics and information management.

Ms Nicola Falcon - General Manager Forecasting, AEMO

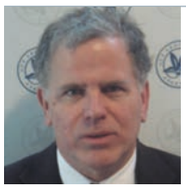
Nicola Falcon heads the Australian Energy Market Operator's Forecasting division and is responsible for demand and supply forecasting for both electricity and gas. She is also responsible for delivering integrated system modelling and cost benefit analyses for AEMO's Integrated System Plan, and reliability assessments to provide decision support for AEMO's planning and operations teams, and industry. Nicola has a background in operations research, and has nearly 20 years' experience in the energy sector specialising in providing strategic advice on issues relating to electricity markets and systems, backed by robust market modelling, statistical, economic and commercial analysis.

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 focussed 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, Fifth, and Sixth Assessment reports and various IPCC Special Reports, sharing the 2007 Nobel Peace Prize with other IPCC participants and Al Gore. Mark has also 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.



Mr Gene McGlynn - Executive Director, Climate Change & Sustainability, ACT Government

Gene McGlynn started as Executive Director, Climate Change and Sustainability, in the ACT Government in July 2018. In this role, he looks after a range of policies and programs to ensure the ACT meets its emission reduction goals while improving the environment and helping all citizens make the transition to a net zero emissions future. Prior to this, Gene worked as a consultant and for more than 20 years worked for the Australian government in climate change and energy policy. He has worked in renewable energy, energy efficiency, transport, building policy and energy markets. He has also worked internationally at the OECD in Paris and the Energy Charter Secretariat in Brussels. .

Ms Fiona Wright - Group Manager, Strategic Safety and Risk, ActewAGL

Fiona Wright is Group Manager of Strategic Safety and Risk at ActewAGL, and is a former Acting General Manager of Evoenergy. In her role at ActewAGL, she was responsible for the management of ACT's electricity and gas networks, including network planning, design and operations. Starting with the business as a cadet engineer in 1993, Fiona has over 20 years' experience in the energy industry. She understands the complexities of the regulatory environment and the importance of agility in a rapidly changing energy landscape. She's passionate about delivering lasting and innovative energy ecosystems designed for consumers. She holds a Bachelor of Engineering (Electrical) and a Master of Business.

EXECUTIVE MEMBERSHIP

Professor Ken Baldwin - ANU College of Science

Professor Ken Baldwin is the inaugural Director of the Australian National University's (ANU) Energy Change Institute, an inaugural ANU Public Policy Fellow, and Director of the ANU Grand Challenge: Zero-Carbon Energy for the Asia-Pacific. The main focus of his work is to help drive the energy transition, particularly for Australia's future export industries based on renewable energy. 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 Sara Bice - ANU College of Asia and the Pacific

Sara Bice is Professor at the Crawford School of Public Policy, The Australian National University. She is Vice Chancellor's Futures Scheme Senior Fellow for her work on The Next Generation Engagement program, Australia's largest study into community engagement in infrastructure, to date. She is President of the International Association for Impact Assessment, the world's leading organisation for impact assessment practitioners, researchers and clients, representing almost 7,000 members in 120 different countries.

Professor Lachlan Blackhall - ANU College of Engineering and Computer Science

Lachlan Blackhall is ANU Entrepreneurial Fellow and Head, Battery Storage and Grid Integration Program. He holds a BE, BSc and a PhD in engineering and applied mathematics and was the co-founder and former Chief Technical Officer of Reposit Power. At Reposit, he pioneered the development of distributed control systems to monitor, optimise and control grid-connected energy storage, as well as the development of virtual power plant technology to aggregate distributed energy storage to deliver services and capabilities to energy networks, markets and utilities. Lachlan has been heavily involved in the entrepreneurship, innovation, technology and investment domains for almost two decades.

Professor Andrew Blakers - ANU College of Engineering and Computer Science

Andrew Blakers 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 Australian Institute of Energy, and the Institute of Physics. He has published 200 papers and patents with research interests in the areas of photovoltaic and solar energy systems. He is also interested in sustainable energy policy, and is an ANU Public Policy Fellow. 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).

Professor Kylie Catchpole - ANU College of Engineering and Computer Science

Professor Kylie Catchpole 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 8,000 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 Professor Catchpole 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.

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 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 is 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).

Professor Frank Jotzo - ANU College of Asia and the Pacific

Frank Jotzo is Professor at the ANU Crawford School of Public Policy, where he directs the Centre for Climate and Energy Policy. He is co-director of the Australia-Germany Energy Transition Hub, joint editor-in-chief of the journal Climate Policy, and a lead author of the Intergovernmental Panel on Climate Change 5th and 6th Assessment Reports. He has been involved in a number of policy research and advisory exercises, including as senior advisor to Australia's Garnaut Climate Change Review, and advisor to national governments and Australian State and Territory governments.

Dr James Prest - ANU College of Law

Dr Prest is an environmental lawyer with more than 25 years' post qualification experience from positions in academia, private sector large law firms, public sector, and NGO legal practice. His primary expertise is in national level sustainable energy law and policy for deep decarbonisation. Dr Prest's expertise is recognised outside of academia, particularly through his work with government, both at the State and Federal levels.

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

Dr 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 abroad. Igor is a convenor of the Master of Energy Change, a Board Member of the Australian Photovoltaic Institute, and the APEC Sustainable Energy Centre in China.

ECI MEMBERS

Artificial Photosynthesis

Professor Elmars Krausz	ANU College of Science
Professor Mark Humphrey	ANU College of Science
Professor Robert Stranger	ANU College of Science
Dr Nick Cox	ANU College of Science
The late Emeritus Professor Ron Pace	ANU College of Science
Professor David Ollis	ANU College of Science
Dr Robin Purchase	ANU College of Science
Dr Hemant Kumar Mulmudi	ANU College of Engineering and Computer Science

Carbon Capture, Utilisation and Storage

Professor Adrian Sheppard	ANU College of Science
Professor Amanda Barnard	ANU College of Science
Professor Justin Borevitz	ANU College of Science
Professor Stewart Fallon	ANU College of Science
Dr Anna Herring	ANU College of Science
Professor Mark Knackstedt	ANU College of Science
Professor Tim Senden	ANU College of Science
Dr Zongyou Yin	ANU College of Science
Professor Sean Smith	ANU College of Science
Associate Professor Rowena Ball	ANU College of Science
Associate Professor Penny King	ANU College of Science
Dr Mohammad Saadatfar	ANU College of Science
Dr Xiaolin (Shannon) Wang	ANU College of Science
Dr Nicholas White	ANU College of Science

Energy and Security

Dr Jessie Moritz	ANU College of Arts and Social Sciences
Associate Professor Llewelyn Hughes	ANU College of Asia and the Pacific
Professor John Blaxland	ANU College of Asia and the Pacific
Professor Quentin Grafton	ANU College of Asia and the Pacific
Dr Elizabeth Boulton	ANU College of Science
Professor Brendan Taylor	ANU College of Asia and the Pacific
Adjunct Professor Chris Barrie	ANU College of Asia and the Pacific
Professor Roger Bradbury	ANU College of Asia and the Pacific
Associate Professor Christian Downie	ANU College of Asia and the Pacific
Dr William Grant	ANU College of Science
Professor Rory Medcalf	ANU College of Asia and the Pacific
Dr Yixiao Zhou	ANU College of Asia and the Pacific

Energy Economics and Policy

Associate Professor Paul Burke	ANU College of Asia and the Pacific
Professor Frank Jotzo	ANU College of Asia and the Pacific
Professor Robert Breunig	ANU College of Asia and the Pacific
Professor Bruce Chapman	ANU College of Asia and the Pacific
Professor Robert Costanza	ANU College of Asia and the Pacific
Professor Quentin Grafton	ANU College of Asia and the Pacific
Professor Kaliappa Kalirajan	ANU College of Asia and the Pacific
Dr Priya Dev	ANU College of Business & Economics
Associate Professor Ida Kubiszewski	ANU College of Asia and the Pacific
Associate Professor Maria Racionero	ANU College of Business and Economics
Honorary Associate Professor Simon Corbell	ANU College of Engineering and Computer Science
Honorary Associate Professor Hugh Saddler	ANU College of Asia and the Pacific
Honorary Professor John Hewson	ANU College of Asia and the Pacific
Dr Zsuzsanna Csereklyei	ANU College of Asia and the Pacific
Dr Matthew Dornan	ANU College of Asia and the Pacific
Dr Jessie Moritz	ANU College of Arts and Social Sciences
Dr Imran Habib Ahmad	ANU College of Science
Dr Emma Aisbett	ANU College of Asia and the Pacific
Associate Professor Christian Downie	ANU College of Asia and the Pacific
Associate Professor Carolyn Hendriks	ANU College of Asia and the Pacific
Associate Professor Llewelyn Hughes	ANU College of Asia and the Pacific
Associate Professor Andrew Kennedy	ANU College of Asia and the Pacific
Professor Warwick McKibbin	ANU College of Asia and the Pacific
Adjunct Professor Robert McMullan	ANU College of Asia and the Pacific
Dr John (Jack) Pezzey	ANU College of Science
Professor Martin Richardson	ANU College of Business and Economics
Professor David Stern	ANU College of Asia and the Pacific
Dr Thang Do	ANU College of Asia and the Pacific
Dr Jorrit Gosens	ANU College of Asia and the Pacific
Dr Reza Fazeli	ANU College of Engineering and Computer Science
Dr José Iria	ANU College of Engineering and Computer Science
Dr Thomas Longden	ANU College of Asia and the Pacific
Dr Mousami Prasad	ANU College of Asia and the Pacific
Associate Professor Ben Phillips	ANU College of Arts and Social Sciences
Professor Israr Qureshi	ANU College of Business and Economics
Professor Ligang Song	ANU College of Asia and the Pacific

Energy Efficiency

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