Australian National University

THE STATE-OF-ENERGY-RESEARCH CONFERENCE

3–4 JULY 2019

SOERC

Organised by

Energy Research Institutes Council for Australia (ERICA)

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Australian National University

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En PURE INTEL AUSTRALIAN ENERGY DAILY

Cover image: Taralga Wind Farm, NSW, Image by James Prest

Image on this page: Noor Ouarzazate solar facility in Morocco (image, Ken Baldwin)

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CHAIR'S WELCOME

Dear SoERC Delegates:

Welcome to the inaugural research-only energy conference in Australia dedicated to promoting the latest leading-edge research across all energy disciplines, ranging from science, engineering and technology to economics, governance and sociology.

The State-of-Energy-Research Conference brings together the latest developments in energy research in one place over two days, providing key energy stakeholders with a broad overview across the entire research spectrum. We hope that this will be the first of a series of conferences that enable researchers and practitioners to keep across the latest advances in the energy field.

SoERC is hosted by the Energy Change Institute of the Australian National University, and is organised by ERICA - the Energy Research Institutes Council for Australia – representing 12 university-based energy research centres.

The Conference would like to express its gratitude to the Conference sponsors: the Australian Energy Market Operator (AEMO) and Origin Energy, as well as to our media partner Australian Energy Daily.

Over the next two days, you will hear from prominent research leaders who will provide overview presentations in each of the conference themes:

- Professor Ross Garnaut, University of Melbourne (Energy Economics & Policy)
- Professor Martin Green, University of New South Wales (Renewable Electricity Generation)
- Professor Maria Forsyth, Deakin University (Energy Storage)
- Dr Lachlan Blackhall, The Australian National University (Energy Systems)
- Dr Chris Dunstan, University of Technology, Sydney (Energy Usage and Demand Response)
- Dr Bruce Mountain, Victoria University (Energy Regulation and Governance)
- Professor Michael Brear, University of Melbourne (Transport and Industrial Energy)
- Professor Peta Ashworth, University of Queensland (Fossil Fuels)

These will be followed by keynote talks providing detailed research findings in the conference themes.

We would also like to emphasise the opportunity to discuss with poster presenters their specialist research achievements at the Wednesday poster session and during all the refreshment breaks.

Each day of the conference will be opened by a presentation from a prominent leader in the energy sector. Sarah McNamara, CEO of the Australian Energy Council, will open the first day of the conference, and Drew Clarke, chair of the AEMO board, will open the second day.

At Wednesday's industry discussion panel, prominent practitioners will examine The Future of Energy Storage. The panel will include Leeanne Bond from Snowy 2.0, Thomas Maschmeyer from University of Sydney, Cameron Potter from Hydro Tasmania, Damien Sanford from AEMO and Ken Tregonning from ETR Solar.

During the lunch break on Thursday, we are pleased to host a Women in Energy lunch, where the deputy-chair of the Women in Energy Network, Kate O'Carroll from AusNet, will present the luncheon keynote address.

The conference is also pleased to offer child care facilities to those delegates who may wish to avail themselves of this option.

We trust that you'll also enjoy the many opportunities for discussions during the refreshment breaks, the lunches and the poster session on Wednesday evening, followed by the Conference Dinner.

We hope that SoERC will enhance your knowledge of the frontiers of energy research, expand your network of key energy contacts, and encourage you to spread the word to your colleagues and wider networks so that we can bring the State-of-Energy-Research Conference to an even larger cross-section of the energy community in future years.

Best wishes,

Professor Ken Baldwin

SoERC General Chair

Image on opposite page: Big Dish Solar Concentrator Facility, The Australian National University

ENERGY RESEARCH INSTITUTES COUNCIL FOR AUSTRALIA (ERICA)

ERICA is a council of university research institutes

Collectively ERICA aims to provide:

- National capacity across a broad spectrum of cutting-edge energy research, in both specialised and inter-disciplinary fields;
- High-level, evidence-based, energy policy advice to government;
- An over-the-horizon perspective on future energy opportunities and challenges that can only be informed by cutting-edge research;
- A research touch point for industry and government on energy issues of national and international significance; and
- A research-led education network for students and young researchers.

As active members of ERICA, participants agree to:

- Meet at least once per year in person;
- Attend teleconference meetings to discuss intervening and time-dependent issues requiring a collective response;
- Provide sufficient resources to enable part-time administrative support for ERICA, including a website and organisation for an annual Energy Research conference;
- Contribute to specific projects on an 'as needs' basis.

Membership of ERICA by any organisation is by invitation through the agreement of existing members, and membership can be requested at any time.

The membership is non-binding, and the consensus views represented by the Council are those of the ERICA representatives and not of their parent universities.

The ERICA secretariat will move from one member institute to the other, each year. The Australian National University is the secretariat for the current year (2018-19).

For more information, contact ERICA Chair 2018/19:

Professor Kenneth Baldwin
Director, Energy Change Institute,
The Australian National University

kenneth.baldwin@anu.edu.au
+61 (0)2 6125 4702

The current members of ERICA

Centre for Energy Technology

The University of Adelaide

Centre for Sustainable Energy Development

The University of Sydney

Deakin Energy

Deakin University

Energy Change Institute

The Australian National University

Fluid Science and Resources Division

The University of Western Australia

Fuels and Energy Technology Institute

Curtin University

Future Energy

University of Tasmania

Melbourne Energy Institute

The University of Melbourne

Monash Energy Materials and Systems Institute

Monash University

University of Queensland Energy Initiative

The University of Queensland

Institute for Sustainable Futures

University of Technology, Sydney

UNSW Energy Institute

The University of New South Wales


THE UNIVERSITY
of ADELAIDE


Curtin University


THE UNIVERSITY OF
SYDNEY


POSTERA CRESCAM LAUDE
THE UNIVERSITY OF
MELBOURNE


DEAKIN
UNIVERSITY


MONASH
University


NATURAM PRIMUM COGNOSCERE RERUM
Australian
National
University


THE UNIVERSITY
OF QUEENSLAND
AUSTRALIA


THE UNIVERSITY OF
WESTERN
AUSTRALIA


UTS


UNIVERSITY of
TASMANIA


UNSW
AUSTRALIA

EVENT INFORMATION

Registration

Registration will occur at all times of the conference period but delegates are encouraged to do so between 8.00 – 8.30am on 3 July 2019 at the information desk in the foyer of the Cultural Centre.

If you have purchased the one-day conference package and need assistance to buy a ticket for the conference dinner or another one-day conference package, please ask the staff.

All student delegates are requested to carry their proof of enrolment at all times of the conference.

Information desk

The foyer information desk at the Cultural Centre will be staffed at all times for your assistance.

Parking

ANU Kambri Union Court Car Park

Ticketless Parking System Guide

1. The system scans your licence plate as you enter the car park.
2. Park your vehicle. When ready to leave proceed to a pay station before collecting your vehicle. Alternatively, payment can be made at the exit gate by Credit Card.
3. At the exit, the camera will scan your licence plate, verify your payment and raise the boom gate.

Taxis

ACT Cabs 02 6280 0077

Staff at the information desks can also provide assistance for booking taxis.

Accessibility

Kambri is located in the centre of the Australian National University. It is connected to Canberra's city centre via University Avenue. The Cultural Centre and the Marie Reay Teaching Centre are connected via Caroline Lane Walk, a lane that intersects University Avenue at the centre of the precinct. The Cultural Centre is accessible on one end via an archway next to bookstore Harry Hartog. The entrance to the Marie Reay Teaching Centre can be found at the opposite end of the lane, next to Chifley Library. Access from Kambri underground car park can be found from either the stairs or elevator located at the carparks centre.

Wi-fi

Network: KambriEvents

Password: 153Tangney

Contacts

The following members are available to assist you. Please do not hesitate to call them.

General enquiries

Aarti Sharad Seksaria

0431 625 674

Communication and Media

Sarah Wilson

0478 563 281

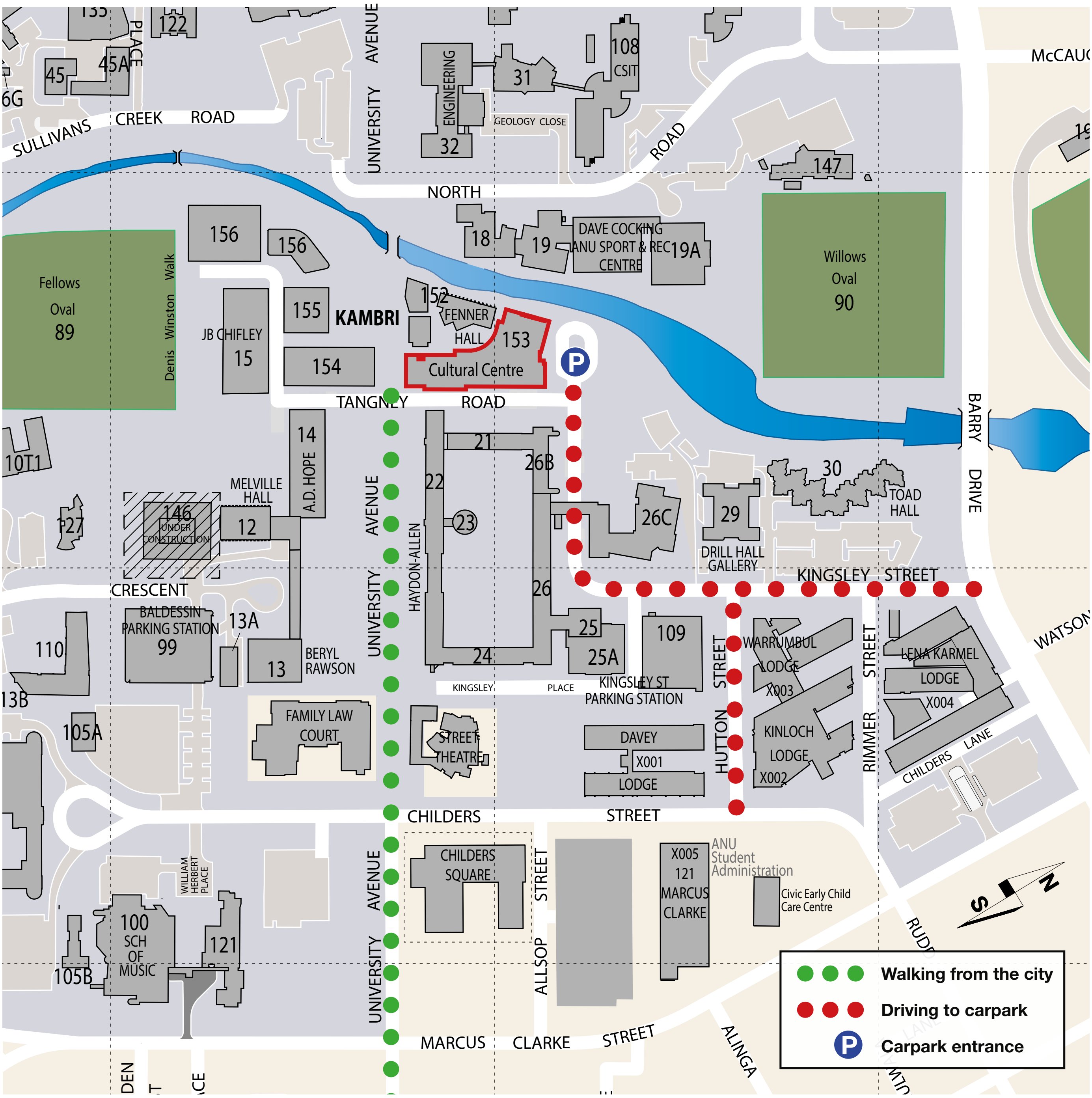
Parking enquiries

Care Park

02 9299 6767

nswsales@carepark.com.au

MAP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PROGRAM

Wednesday 3 July

CC – Cultural Centre TB – Teaching Building

8.00 am	CC Foyer	Registrations				
8.30 am	CC Cinema Theatre	Opening plenary address	**Sarah McNamara** Chief Executive, Australian Energy Council			
9.00 am		Plenary presentation and discussion panel	**Renewable Electricity Generation** by Martin Green, the University of New South Wales			
10.00 am			**Energy Storage** by Maria Forsyth, Deakin University			
11.00 am	CC Foyer	Morning tea & Poster viewing				
11.30 am	TB Level 5	Parallel keynote talks	**Solar**	**Batteries**	**Energy Economics and Finance**	**Transitional Policy**
		Speaker 1	Kylie Catchpole, ANU	Alexey Glushenkov, ANU	Paul Dowling, CEFC	Sara Bice, ANU
		Speaker 2	Gus Nathan, UofA	Andrew MacKenzie, Envirostream	Christian Downie, ANU	Paul Stanwix, UWA
		Speaker 3	Doojin Vak, CSIRO	Maria Skyllas-Kazacos, UNSW	Gordon Leslie, Monash University	John Wiseman, UoM
12.30 pm	CC Foyer	Lunch & Poster viewing				
1.30 pm	CC Cinema Theatre	Industry panel discussion	**The Future Role of Energy Storage** Leeanne Bond (Snowy 2.0), Thomas Maschmeyer (University of Sydney), Cameron Potter (Hydro Tasmania), Damien Sanford (AEMO) and Ken Tregonning (Emergent Technologies Resources PL)			
2.30 pm		Plenary presentation and discussion panel	**Energy Usage and Demand Response** by Chris Dunstan, the University of Technology, Sydney			
3.30 pm	CC Foyer	Afternoon tea & Poster viewing				
4:00 pm	CC Cinema Theatre	Plenary presentation and discussion panel	**Energy Systems** by Lachlan Blackhall, The Australian National University			
5.00 pm	TB Level 5	Parallel keynote talks	**Wind and other**	**Pumped hydro and Hydrogen technologies**	**Climate and Energy Policy**	**Grid Integration**
		Speaker 1	Keith Ayotte, Windlab	Fiona Beck, ANU	Frank Jotzo, ANU	Iain MacGill, UNSW
		Speaker 2	Adi Paterson, ANSTO	Andrew Blakers, ANU	Heather Lovell, UTas	Elizabeth Ratnam, ANU
		Speaker 3	Matt Stocks, ANU	Mark Paskevicius, Curtin University	Tony Wood, Grattan Institute	Gregor Verbic, USyd
6.00 pm	CC Foyer	Networking and Poster session				
7.30 pm	TB Superfloor	Conference dinner: Speaker	**Andreas Loeschel** Chair, Commission for the Monitoring of the Energy Transition (Germany) and, Co-Director, Australian-Germany Energy Transition Hub.			

Thursday 4 July

CC – Cultural Centre TB – Teaching Building

8.30 am	CC Cinema Theatre	Opening plenary address	**Drew Clarke** Chair, AEMO			
9.00 am		Plenary presentation and discussion panel	**Energy Economics & Policy** by Ross Garnaut, University of Melbourne			
10.00 am			**Energy Regulation & Governance** by Bruce Mountain, Victoria University			
11.00 am	CC Foyer	Morning tea & Poster viewing				
11.30 am	TB Level 5	Parallel keynote talks	**Efficiency and Usage**	**NEM Redesign**	**EVs & Fuel Cell Vehicles**	**Optimisation**
		Speaker 1	Sangeetha Chandra-Shekeran, UoM	Iain MacGill, UNSW	Llewelyn Hughes, ANU	Ian Hiskens, UMichigan
		Speaker 2	Sarea Coates, DoEE	Tim Nelson, AEMC	David Viano, CSIRO	Nando Ochoa, UoM
		Speaker 3	Leslie Martin, UoM	Alex Wonhas, AEMO	Jake Whitehead, UQ	Maria Vrakopoulou, UoM
12.30 pm	CC Cinema Theatre	Women in Energy Lunch Speaker	**Kate O' Carroll** Ausnet Services			
1.30 pm		Plenary presentation and discussion panel	**Transport and Industrial Energy** by Michael Brear, The University of Melbourne			
2.30 pm			**Fossil Fuels** by Peta Ashworth, The University of Queensland			
3.30 pm	CC Foyer	Afternoon tea & Poster viewing				
4.00 pm	TB Level 5	Parallel keynote talks	**Demand Response**	**Gas Markets**	**Renewable Fuels**	**Carbon Capture and Storage**
		Speaker 1	Gerard Ledwich, QUT	Justine Lacey, CSIRO	Chun-Zhu Li, Curtin University	Ralf Haese, UoM
		Speaker 2	Yolande Strengers, Monash University	Ross Lambie, DoEE	Yun Liu, ANU	Anna Herring, ANU
		Speaker 3	Phillippa Watson, UTas	Xunpeng Shi, UTS	Thomas Maschmeyer, USyd	Linda Stalker, CSIRO
5.00 pm	CC Foyer	Networking session				
6.00 pm		Conference Close				

SoERC LOCAL ORGANISING COMMITTEE

The Australian National University

Dr. Christian Downie

Fellow
ANU College of Asia and the Pacific

Dr. Matthew Stocks

Research Fellow
ANU College of Engineering and Computer Science

Dr. Fiona Beck

FERL Fellow, ARC DECRA Fellow, Senior Lecturer
ANU College of Engineering and Computer Science

Dr. Rebecca Colvin

Lecturer
Crawford School of Public Policy

Professor Frank Jotzo

Professor, Crawford School of Public Policy; Director,
Centre for Climate Economics & Policy
ANU College of Asia and the Pacific

Associate Professor Sara Bice

Senior Fellow
Crawford School of Public Policy

Dr. Lachlan Blackhall

Entrepreneurial Fellow
Head, Battery Storage & Grid Integation
ANU College of Engineering and Computer Science

OPENING SPEAKERS

Wednesday 3 July

Sarah McNamara

Sarah McNamara was appointed as Chief Executive of the Australian Energy Council in July 2018.

Sarah joined the Energy Council as General Manager of Corporate Affairs in January 2016. She is an industry leader with more than a decade of experience working with policy and regulatory frameworks across the resources and energy sectors.

Prior to the Energy Council, Sarah was Chief of Staff to the then Minister for Industry, the Hon Ian Macfarlane, and has also worked as a senior policy adviser to the Prime Minister.

Between 2008 and 2013 Sarah worked in AGL's Corporate Affairs team as Head of Government Affairs and Community Engagement. Sarah began her career as a corporate lawyer, and has a Bachelor of Arts/Law from the University of Melbourne.

Thursday 4 July

Drew Clarke AO

Mr Clarke has held leadership roles in Australian energy policy since 2003. From 2003 to 2013, he served in progressively more senior Commonwealth positions including terms as Deputy Secretary and Secretary of the Department of Resources and Energy.

During this period, Mr Clarke led the Commonwealth's actions in the creation of the National Energy Market Rules and the three market bodies, served as the Chair of the Senior Committee of Officials (Commonwealth, State, Territory) under the COAG Ministerial Council on Energy, and led national and international energy policy development for Australia, including on climate change and resource development. He led the establishment of the Australian Renewable Energy Agency (ARENA) and the Global Carbon Capture and Storage Institute, and was Australia's member on the Governing Board of the International Energy Agency.

Mr Clarke has also served as Secretary of the Department of Communications, and as Chief of Staff in the Office of the Prime Minister. Drew is currently Chairman of the Australian Energy Market Operator (AEMO), and a Director of NBN Co and CSIRO.

Mr Clarke was awarded an Order of Australia in 2016 for distinguished service to public administration, and is a Fellow of the Academy of Technological Sciences and Engineering.

CONFERENCE DINNER SPEAKER

Wednesday 3 July

Andreas Loeschel

Professor Andreas Loeschel holds a Chair for Energy and Resource Economics and is director of the Center of Applied Economic Research at the University of Münster, Germany. Since 2011 he has been the chairman of the Expert Commission of the German Government to monitor the energy transformation. He also directs the Virtual Institute Smart Energy North Rhine-Westphalia (VISE). Andreas Loeschel is a Lead Author of the Intergovernmental Panel on Climate Change (IPCC) for the Fifth and Sixth Assessment Report (2010-21) and a member of the German National Academy of Science and Engineering (acatech). He is currently a visiting researcher at the Crawford School of Public Policy, Australian National University, and a co-director of the Australian-German Energy Transition Hub. In the Frankfurter Allgemeine Zeitung (F.A.Z.) economist ranking he was several times among the 50 most influential economists in Germany. He received his PhD in Economics at the University of Mannheim in 2003.

INDUSTRY PANEL DISCUSSION: THE FUTURE ROLE OF ENERGY STORAGE

Leeanne Bond

Leeanne Bond has 30 years corporate experience including over 14 years as a professional company director with a particular focus on energy and utilities.

Leeanne is a non-executive director of the Clean Energy Finance Corporation, Snowy Hydro Limited and ASX listed Liquefied Natural Gas Limited and non-executive chairman of ASX listed Synertec Corporation Limited. She is also on the board of University of Queensland's JKTech Pty Ltd and QADO Services Pty Ltd.

Leeanne has a Bachelor of Chemical Engineering and an MBA from The University of Queensland and is a Fellow of the Australian Institute of Company Directors. She is a Chartered Professional Engineer and an Honorary Fellow of Engineers Australia. Leeanne has recently been elected as a Fellow of the Australian Academy of Technology and Engineering.

Thomas Maschmeyer

Thomas is Professor of Chemistry at the University of Sydney. He was elected youngest Foreign Member of the Academia Europea, and holds Fellowships of the Australian Academy of Sciences, the Australian Academy of Technological Sciences and Engineering, the Royal Australian Chemical Institute and the Royal Society of NSW.

He is Founding Chairman of *Gelion Technologies* (batteries), co-founder of *Licella Holdings* (bio- and plastic waste conversions) and of *Avantium* (bio-plastics, high-speed experimentation).

He published 320+ items (H-Index 54), including 26 patents. He serves on the editorial/advisory boards of ten international journals and received many awards, including the Eureka Prize for Leadership in Innovation and Science (2018) – Australia's "Science Oscar"; the RACI R. K. Murphy Medal for Industrial Chemistry (2018); the NSW Science & Engineering Award for Renewable Energy Innovation (2013), the RACI Weickhardt Medal for Economic Contributions (2012); the RACI Applied Research Award (2011) and the Le Févre Prize of the Australian Academy of Sciences (2007).

Cameron Potter

A passion for data driven decision making and being at the edge of new technology has driven Cameron Potter's career.

Cameron works at Hydro Tasmania and leads the Future State NEM analysis for the *Battery of the Nation* initiative – exploring the potential for Tasmania to play a substantially larger role in the National Electricity Market.

This is directly applicable to the Integrated System Plan. Cameron is leading efforts to establish a working group between AEMO, TasNetworks and Hydro Tasmania to improve the modelling of the Tasmanian energy system's potential under further interconnection.

He has championed risk-driven analysis of renewable energy, power system integration studies, and research and product development related to wind and solar energy modelling for commercial and/or government purposes.

Damien Sanford

Damien Sanford is the Executive General Manager (EGM), Operations, with responsibilities for AEMO's electricity and gas system operations and engineering teams. Damien has extensive experience honed through a variety of operational and advisory roles in energy markets, energy grid operations, emergency and risk management and the armed forces.

Prior to his current role, Damien led various operational functions within AEMO over the past eight years, including most recently senior management roles in real-time electricity and gas operations.

Damien holds a Bachelor of Business Management, is a Member of the Australian Institute of Company Directors and is a former Australian Army Officer where he served in a variety of operational roles over 10 years.

Dr Ken Tregonning

After a PhD in Theoretical Physics and a period in research, including two papers in Nature on Complex Interactive Systems, Ken began working in the energy industry in 1981 with Shell in the Netherlands and Denmark prior to two decades in consulting. His experience spans the globe in the energy sector in corporate and project management, asset evaluation, engineering and financing of projects. He has lived and worked in Europe, UK, Australia and South East Asia as well as done business in USA, India, Central Asia etc. Initially focussed on the upstream oil and gas industry he is now active in the solar electricity industry. He has founded and run companies including two mid-sized ASX listed companies and a solar development company, Emergent Technologies Resources. ETR has large solar-electric projects in Australia as well as a project for conversion of renewable energy to a transportable hydrogen carrier.

Lunch speaker

TITLE

Creating community in your work life

SPEAKER

Kate O'Carroll

ABSTRACT

As women progress in their careers and are trying to 'have it all' we look to those in positions of authority to help steer us. Women don't seem to have the right archetype of 'Authentic Leadership' to draw from and seem to be looking for a lot more guidance than their male counterparts. Forming a work community of smart people, who are employed across the Energy Value Chain has really helped me understand the interrelations of the market, generation, renewables and DERs and how data is forcing these streams to converge. Finding or creating your community, networking and learning from others, can energise you, progress career aspirations and provide an outlet for things that your colleagues, or people in your home life may not understand.

Kate is vice chair of Women in Energy, a not-for-profit organisation addressing the gap in female leadership within the energy industry in Australia. The mission of Women in Energy is to enable women to advance their careers in the energy sector by delivering education, training, advocacy and networking. Women in Energy regularly hosts networking and technical events, with Kate establishing the Women in Power Breakfasts.

Kate currently works at AusNet Services on projects in future grid management, demand management and energy education that are helping transform the distribution network to a higher penetration DER future. Kate has over 8 years' experience in project management in DER R&D and Transmission and Distribution sector, where she managed the design component of augmentation works across multiple switchyard and substations, including emergent Ground Fault Neutraliser technology. Kate has a MEng Architecture and Environmental Design (Hons.) from the University of Nottingham, UK.

Plenary presentation and discussion panel

TITLE

Photovoltaics: Recent progress and future prospects

SPEAKER

Martin A. Green

Martin Green is Scientia Professor at the University of New South Wales, Sydney and Director of the Australian Centre for Advanced Photovoltaics, involving several other Australian universities and research groups. His group's contributions to photovoltaics are well known and include inventing the PERC cell, now the main commercial cell, and holding the record for silicon solar cell efficiency for 30 of the last 36 years, described as one of the "Top Ten" Milestones in solar photovoltaics history. Major international awards include the 1999 Australia Prize, the 2002 Right Livelihood Award, also known as the Alternative Nobel Prize, and most recently, the 2018 Global Energy Prize presented in Moscow last October.

ABSTRACT

The last five years have seen major reductions in silicon solar module prices, with these dropping at a compounded rate of 20%/year over this period, with even more dramatic reductions in bids for bulk electricity supply through Power Purchase Agreements, to values as low as US$17.86/MWh. On the technology front, there have been substantial improvements in module energy conversion efficiency through displacement of established cell technology by the UNSW-invented and -developed PERC cell, complemented by the introduction of multi-busbar and half-cell modules. The introduction of PERC cells also allows low-cost fabrication of bifacially responsive modules, set to further boost effective efficiencies. These developments position photovoltaics to make a major impact on global CO^2 emissions, with ANU studies showing no barriers to Australia's transition to 100% renewable electricity supply using existing technology. A recent international study takes this a step further, showing a path to a zero carbon future by 2050 by technology transition across all major energy sectors including not only electricity, but also heat, transport and industrial processes. This transition is driven primarily by solar, with 63TW capacity calculated as required globally by this date, complemented by 8TW of wind, in the process creating 35 million direct energy jobs.

DISCUSSANTS

Keith Ayotte and Gus Nathan

Keynote speakers

TITLE

Perovskite/silicon tandem solar cells for high efficiency photovoltaics

SPEAKER

Kylie Catchpole

ABSTRACT

In recent years the price of solar electricity has dropped lower than the price of conventional electricity, and globally renewables now account for more than half of new electricity capacity. The dominant technology for solar is silicon, but silicon has fundamental efficiency limitations. Overcoming those limitations will be key to enabling further decreases in the costs of solar, to allow it to become the leading electricity technology, as well as to open up applications of solar in other sectors. The most promising path to high efficiency is the use of a tandem structure, which allows blue light to be absorbed in one material and red light to be absorbed in another, leading to higher voltage. Combining newly developed perovskite materials with silicon is a particularly attractive option for producing cheap, high efficiency solar cells and this talk will discuss progress to date and prospects for the future.

Kylie Catchpole is Professor in the Research School of Electrical Energy and Materials Engineering at the Australian National University. She has over 100 scientific publications, with a focus on using new materials and nanotechnology to improve solar cells. She completed her PhD at ANU and was a postdoctoral fellow at the University of New South Wales and the FOM Institute for Atomic and Molecular Physics in Amsterdam before returning to ANU in 2008. In 2013 she was awarded a Future Fellowship from the Australian Research Council and in 2015 she was awarded the John Booker Medal for Engineering Science from the Australian Academy of Science.

Keynote speakers

TITLE

Toward fully roll-to-roll printed large-area perovskite solar cells

SPEAKER

Doojin Vak

ABSTRACT

CSIRO is developing manufacturing methods for roll-to-roll printed solar cells, with the ultimate goal of commercialising the technology. To date, conjugated-polymer-based materials have been used exclusively as the photoactive layer of fully roll-to-roll printed large-area solar cells. However, organic-inorganic hybrid perovskites have emerged as a “drop-in” replacement for polymer-based materials. These materials have outstanding optoelectronic properties, such as long carrier diffusion length, high absorption coefficient, and small exciton binding energy. The efficiencies of champion devices have been increasing rapidly, with a record of 23.7 % already reached, which is comparable to that of single crystal Si solar cells (26.1 %). Therefore, this new class of materials has been investigated as an alternative photoactive material using scalable deposition methods, including slot die coating. The presentation will give an overview of the challenges and progress in printed perovskite solar cells. Recent progress on roll-to-roll printed perovskites will also be presented.

Dr Doojin Vak is a Principal Research Scientist working on printed PV in CSIRO, and is currently leading an ARENA-funded R&D project on the “Manufacturing of Printed Perovskite PV Modules”. He received his PhD on organic semiconductors for optoelectronic applications from GIST in Korea. He started research on printed PV at the University of Melbourne in 2007. Since he joined CSIRO in 2010, he has been working on various industrial processes, such as gravure printing, reverse gravure coating, slot die coating and screen printing, for the commercialization of printed organic and perovskite solar cells. He reported the first slot die coated perovskite PV in 2015 and also reported the first roll-to-roll produced perovskite PV in 2017. He was awarded a Korea Research Foundation (KRF) postdoc fellowship in 2007, a CSIRO Julius Award in 2015 and a Distinguished Visiting Professorship from UNIST (Korea) in 2016.

Keynote speakers

TITLE

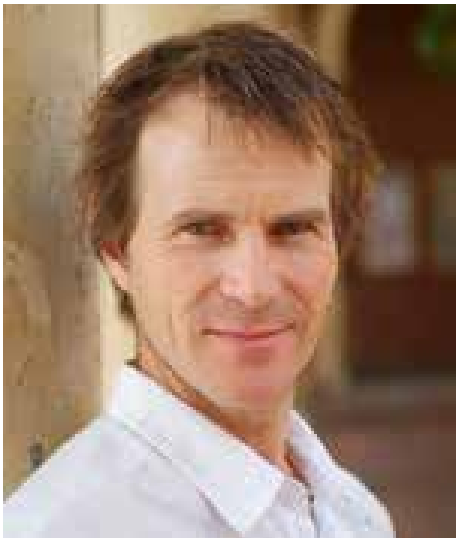
Research in concentrating solar thermal energy for applications in power, heat and fuels

SPEAKER

Gus Nathan

ABSTRACT

Major research programs around the world are developing several parallel technology platforms to achieve stored, high temperature solar thermal energy. These programs are aiming to increase from the ~580ºC at which commercial molten salts can be stored, to systems that achieve storage temperatures of ~750ºC in the near term and ~1000ºC thereafter. These higher temperatures will open the door, not only to more efficient power cycles, but also to applications in which the heat can be used directly to process minerals or to produce solar fuels. The direct use of heat for chemicals and fuels is a particularly exciting opportunity, given that the energy requirements for industrial energy and transport are each of the same order of magnitude as that for electricity. The presentation will address some of the key research challenges and opportunities in these pathways to higher temperature processes and its application, particularly for process heat and fuels.



Professor Nathan is the founding Director of The University of Adelaide's Centre for Energy Technology and recipient of a Discovery Outstanding Researcher Award from the Australian Research Council. He specialises in research supporting the development of innovative technology in concentrating solar thermal, combustion and gasification technologies, together with their hybrids. Gus is leader of Node 4 of the national Australian Solar Thermal Research Initiative, which aims to lower the cost of solar fuels production, and project leader for an ARENA funded project to introduce concentrating solar thermal into the Bayer Alumina process in partnership with Alcoa and Hatch. He is an author of more than 10 patents, including three families of concentrating solar thermal technology, 50 commissioned reports, 150 international journal publications and 200 peer-review conferences.

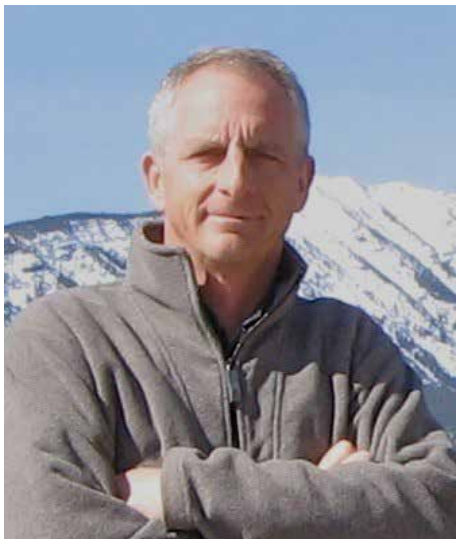
Keynote speakers

TITLE

Two decades of measuring and modelling the wind

SPEAKER

Keith Ayotte



Keith Ayotte is one of the founders and the Chief Scientist at Windlab Limited (www.windlab.com) and has 25 years of experience in the fields of meteorology, wind flow in complex terrain, and computational fluid dynamics. Keith has been a weather forecaster in Atlantic Canada for Environment Canada, a research scientist at the National Center for Atmospheric Research in Boulder, Colorado and before Windlab was a Senior Research Scientist with the Commonwealth Scientific and Industrial Research Organisation (CSIRO). Keith continues to develop and support Windlab's global site identification program and asset management activities and manages all R&D efforts including research and development in Computational Fluid Dynamics, meteorological modelling and Machine Learning research and implementation.

ABSTRACT

Wind Meteorology in renewable energy is centred on measuring and modelling the lowest few hundred metres of the atmosphere. This is done in support of creating annual energy yield predictions and increasingly of late, short- and medium-term forecasts underpinning grid integration. Over the last two decades the Wind Industry has moved from using simple linear flow models in similarly simple methodologies that essentially extrapolate between measurement and turbine locations, to fully nonlinear coupled meso- and micro-scale calculations that use machine learning algorithms as a means of data assimilation. These advances have been underpinned by significant advances in measurement technology. In twenty years we have moved from mast measurements using cup anemometers and wind vanes to SODAR and LIDAR technologies that return profiles of wind speed and direction through the lowest two hundred metres of the atmosphere, all from a relatively small portable device that can be easily deployed and relocated. This talk will highlight progress in Wind Meteorology over the last two decades and give a glimpse of where it is likely to go in the coming years.

Keynote speakers

SPEAKER

Adi Paterson

Adi Paterson is the CEO of ANSTO. Since March 2009 he has had oversight and responsibility for ANSTO's multi-facetted portfolio of activities.

ANSTO is the home of Australia's nuclear science and technology expertise, leveraging great science, partnerships and ingenuity for a more sustainable world. ANSTO provides users with access to landmark and national research infrastructure and partners in research, technology translation and innovation. ANSTO maintains key linkages to the International Atomic Energy Agency, the Nuclear Energy Agency and ITER.

Dr Paterson has experience in key policy areas including science and innovation, energy and the nuclear fuel cycle. He is a Fellow of the Australian Academy of Technology and Engineering (ATSE), Engineers Australia (EA), and the Royal Society of New South Wales.

Keynote speakers

TITLE

Transmission and interconnection – supporters or obstacles for change?

SPEAKER

Matthew Stocks

ABSTRACT

Australia is installing variable renewable energy at rates faster than anywhere else in the world, placing us at the forefront of electricity system change. A reliable grid dominated by variable renewables will depend on demand management, storage and additional transmission to balance supply and demand. Australia is already starting to see significant impact on the transmission network of renewable energy builds including reduced system strength and dropping marginal loss factors. These and other constraints have the potential to slow the transition to a low carbon electricity grid.

This talk will summarise some of the challenges of high penetration of renewables on the transmission network, research activities underway to overcome these issues and opportunities for new development activities in the future.

Dr Matthew Stocks is a Research Fellow ANU College of Engineering and Computer Science. He has more than 25 years research and development experience in renewable energy and photovoltaics. Matthew was Chief Technologist at Transform Solar from 2003-2012, commercialising the ANU invented SLIVER solar cell technology in Adelaide and in the US. His current research efforts are focused on integrating high amounts of renewable energy in Australia's electricity network, enabled through a combination of effective transmission and storage and using renewable electricity to decarbonise the economy. He is part of the research team on the ARENA funded STORES project, mapping pumped hydro opportunities throughout Australia which won the 2018 Eureka Prize for Environmental Science.

Plenary presentation and discussion panel

TITLE

Electrochemical energy storage – beyond 2020

SPEAKER

Maria Forsyth

Professor Maria Forsyth "FAA" (Fellow Australian Academy of Sciences), is the Director of ARC Industrial Transformation Training Centre in Energy Storage Technologies, StorEnergy, past ARC Laureate fellow and currently an Alfred Deakin Professorial Fellow at Deakin University and an Ikerbasque Visiting Professorial Fellow at University of the Basque Country. She is the Associate Director in the ARC Centre of Excellence in Electromaterials Science (ACES) and Deputy Director of the Institute for Frontier Materials (IFM) at Deakin University in Australia, where she leads the research effort in energy storage and corrosion science. Professor Forsyth leads collaborative projects in lithium and sodium battery technologies funded through recent Australian Research Council grants and with industries such as Toyota Nth America and Toyota Japan. She is a co-author of over 550 journal and conference publications that have attracted more than 20000 citations. She has delivered more than 25 invited and plenary talks in the past 5 years. She was one of the team that delivered the ACOLA report "*The Role of Energy Storage in Australia's Future Energy Supply Mix*" to the Chief Scientist in 2017. Professor Forsyth has served on several editorial boards and is currently senior editor for *Journal of Physical Chemistry letters*. She is the recipient of the Galileo Galilee award for her contributions to the Polymer Electrolyte and energy storage field and was awarded The Victorian Prize for Science and Innovation (VESKI) in 2017.

ABSTRACT

Renewable energy technologies are making increasing inroads globally given the imperative of reducing carbon emissions. Over one quarter of the worlds' electricity supply is generated by renewables already, and this is set to continue to rapidly increase in many countries, including Australia. Whilst fossil fuels are likely to continue to have a role in energy generation, the other generation technologies including wind, solar, wave etc, are variable sources and dependent on day/night, weather, seasons etc. It is therefore accepted that energy storage must exist hand in hand with renewables. This storage can be based on water, chemical, thermal and electrochemical processes. Each of these must, and will, play a role in the future. The ideal storage method will depend on a given situation; whilst pumped hydro is perfectly suited to certain geographical features and hydrogen (in the form of H2 or NH3) is an exciting opportunity in particular for export, electrochemical energy storage – i.e. batteries and capacitors - will still play an important role. This is in particular true for remote areas where extended infrastructure does not yet exist and the cost of establishing and maintaining such infrastructure is uneconomical. It is also true for distributed systems where customers want more control over their energy supply, for example in cases of individual, self-sufficient homes or industries or even communities on a micro-grid. Batteries will also play a role in future energy security. Moreover, more than one battery chemistry is already available and more are set to hit the market. Again, different applications call for different technologies. As an example, cold climate versus hot humid conditions could be better suited to different chemistries.

DISCUSSANTS

Matthew Stocks and Mark Paskevicius

BATTERIES

Keynote speakers

TITLE

Status of potassium-ion batteries globally and in Australia

SPEAKER

Alexey Glushenkov

ABSTRACT

Potassium-ion batteries represent one of the sustainable alternatives to the currently dominant lithium-ion battery technology. This type of battery offers high voltage cells based on naturally abundant ionic shuttle, and the field has developed very fast since 2015. The presentation will show the current status of the potassium-ion battery development globally and in Australia, with the focus on available electrode materials.

Graphite has emerged as a promising anode material in potassium-ion batteries. Similarly to its behaviour with lithium, it can reversibly intercalate potassium ions at low potentials. Other possible anode materials (based on anticipated alloying and conversion-alloying reaction mechanisms) are identified. It is revealed that the mechanisms of electrochemical reactivity with potassium are different from those established in lithium cells.

Metalorganic frameworks, layered and polyanionic inorganic compounds are currently investigated as cathode materials by the community. In the later part of the talk, an overview of known cathode materials will be presented and the openly available information on full cell battery prototypes will be discussed.

Dr Alexey M. Glushenkov is a Fellow in the Battery Storage and Grid Integration Program at the Australian National University. He is a research leader in battery materials within this initiative. Previously, Dr Glushenkov had research appointments at Boreskov Institute of Catalysis (Russia), Australian National University, Deakin University, Melbourne Centre of Nanofabrication, the University of Melbourne as well as Drexel University (the US). His research interests are centred on electrochemical energy storage in metal-ion batteries, electrochemical supercapacitors and hybrid metal-ion capacitors as well as materials that enable these energy storage cells. He was a winner of the 2014 Vice-Chancellor's Award for Research Excellence at Deakin University (early career researcher) and was a 2017 Emerging Investigator of Journal of Materials Chemistry A. Since 2016 Dr Glushenkov serves as an associate editor of RSC Advances (Royal Society of Chemistry, the UK).

Keynote speakers

TITLE

The opportunities and challenges of battery recycling in Australia

SPEAKER

Andrew Mackenzie

ABSTRACT

Envirostream is Australia's first lithium ion battery and mixed chemistry battery recycling company. Andrew Mackenzie is the founder and designer behind Envirostreams' processing of end-of-life batteries to extract reusable commodities to put back into the manufacturing industry.

Andrew's presentation is on the current state of battery recycling in Australia. His presentation will cover topics to do with the circular economy, product stewardship, engineering in the recycling sector, resources recovered, issues of today, opportunities and where recycling of batteries fits in the circular economy.

Topics will cover in broad detail the size of this growing waste stream and the hazards of doing nothing also the opportunity for leadership, collaboration, future opportunities, and research that is needed.

We must also consider end-of-life, circular economy and ethical supply principles when choosing an energy storage technology for larger scale applications. If LIBs were used for every energy storage application then we would also run in to a criticality of supply in regard to Li and other elements including Co. Na and flow battery technologies certainly offer a more sustainable, and ultimately less expensive, option for larger scale storage and other applications where the highest energy density offered by some Lithium technologies is not mandatory. Significant research is still needed to develop the alternative technologies as well as develop sustainable methods for existing and future technologies. An overview of current and future technologies and Australia's possible role in these will be discussed.

Andrew Mackenzie is the founder of Envirostream Australia Pty Ltd and the director of PF Metals Pty Ltd, with over 20 years industrial processing and manufacturing experience.

Currently, as the director of two resource recovery companies; Andrew overseas operations which are primarily focused on maximising ferrous and non-ferrous metal recovery at PF Metals, and Australia's first lithium, alkaline and nickel metal hydride battery processor, Envirostream Australia. Andrew spent over two years researching and prototyping the processing equipment before Envirostream began its operations in early 2017 with the vision of increasing the low battery recycling rate in Australia through continuous innovation and on-shore processing capacity.

Previously, Andrew owned and operated an industrial machinery manufacturing business. The range of machines built were for manufacturing in a range of industries from food processing, woodworking and steel fabrication. This has given Andrew a strength in a wide range of processes that can be applied in unique ways to current and future projects.

Andrew also travels to all the downstream partners to ensure best practice is constant and innovation discussions continue in processing, quality and end market developments for the products in which his companies produce.

Keynote speakers

TITLE

Recent progress and cost considerations of the Vanadium Redox Flow Battery

SPEAKER

Maria Skyllas-Kazacos

ABSTRACT

The All-Vanadium Redox Flow Battery (VRFB) that was initially developed at UNSW Sydney in the mid 1980s, has recently seen considerable commercialisation around the world in a range of energy storage applicaitons. Over the last decade, significant improvements in performance have been achieved through electrode modification and new cell designs that have led to increases in power density and reduced stack costs. In this paper a brief overview of the current status of the VRFB will be presented together with the main advances in electrode materials, cell design and battery control. Results from modelling and simulation studies that can be used to optimise stack design and battery performance will also be presented.

Maria is currently Emeritus Professor in the School of Chemical Engineering, UNSW Sydney where she continues to supervise research projects in energy storage and aluminium smelting. She is a Fellow of the Royal Australian Chemical Institute, a Fellow of the Institute of Engineers Australia and a Fellow of the Australian Academy of Technological Sciences and Engineering. She pioneered the Vanadium Redox Flow Battery that is currently being commercially manufactured by several companies in Japan, USA, China, UK and Germany and is widely regarded as the most appropriate technology for large-scale energy storage in a wide range of applications.

PUMPED HYDRO AND HYDROGEN TECHNOLOGIES

Keynote speakers

TITLE

Storage for 100% renewables

SPEAKER

Andrew Blakers

ABSTRACT

Australia is installing 6-7 GW of wind and solar PV per year. This is fast enough (if continued) to reach 50% renewable electricity in 2024 and thereby meet the Paris greenhouse targets 5 years early. The requirements for supporting 50-100% renewable electricity are straightforward: stronger interstate interconnection to smooth out local weather and large-scale storage, in the form of pumped hydro and batteries.

Andrew Blakers is Professor of Engineering at the Australian National University. His research interests are in the areas of silicon photovoltaic solar cells and solar energy systems. He has extensive experience with basic and applied research and was a leader and first author of the team that developed PERC silicon solar cell technology, which has cumulative module sales of around $40 billion. He is engaged in detailed analysis of energy systems with high (50-100%) penetration by wind and photovoltaics with support from pumped hydro energy storage (for which he was a co-winner of the 2018 Eureka Prize for Environmental Research).

Keynote speakers

TITLE

Rational integration of photovoltaics for solar hydrogen generation

SPEAKER

Fiona Beck

ABSTRACT

Hydrogen generated from renewable sources could be the key to realising decarbonisation of the global energy sector by providing an energy-dense, zero-carbon fuel. In order to meet the needs of the emerging global hydrogen economy, the development of commercially viable solar hydrogen generators needs to be accelerated. Many different hydrogen generators have been demonstrated on a lab-scale, employing photovoltaic (PV) components integrated into the system in a variety of ways, including as photoelectrodes and photoelectrochemical cells. In this talk I discuss how PV technologies can be rationally integrated into solar hydrogen systems to optimise efficiency and leverage the success of existing solar energy technologies, and the maturity of the silicon PV industry, to rapidly advance solar hydrogen generation.

Dr Beck is a Senior Research Fellow at the Research School of Electrical, Energy and Materials Engineering at the ANU, and Convenor of the Hydrogen project for the ANU Grand Challenge: *Zero-Carbon Energy for the Asia Pacific*. Her research spans the boundary between nano-scale optics and optoelectronic device design: harnessing an improved understanding of light-matter interactions to investigate new ways to convert light to other forms of energy, with applications in solar fuels and novel light detection. Dr Beck currently holds a Discovery Early Career Researcher Award (DECRA) from the ARC, as well as the Future Engineering Research Leader (FERL) Fellowship from the ANU.

Keynote speakers

TITLE

Hydrogen storage systems

SPEAKER

Mark Paskevicius

ABSTRACT

The need to store renewable energy becomes more apparent as we transition away from base-load fossil fuels. Hydrogen is a convenient medium for chemically storing energy as it can store the highest energy per mass of any fuel. However, it is a low density gas that takes up a large volume, even when highly compressed. This talk will provide an overview of different methods to store hydrogen that could be used for mobile or stationary energy storage or even for energy export. The global trends in hydrogen storage technology will be discussed with reference to some of the front-running storage solutions and developing options.

Dr Mark Paskevicius is an ARC Future Fellow within the Fuels and Energy Technology Institute at Curtin University (Perth, Australia). His research is centered around developing new methods and materials for energy storage. He is leading the development of next-generation solid-state batteries, which are based on boron-rich solid electrolytes. This technology offers the possibility to increase battery safety, increase energy densities, and potentially allow for new battery chemistries that reduce the cost of batteries. Dr Paskevicius is also developing new materials to store thermal energy for concentrating solar thermal power plants through thermochemical hydrogen-solid reactions at high temperature. Here, the aim is to enable 24/7 electricity production from solar energy, exploiting the strongly endothermic and exothermic reactions between hydrogen and solids to build a ‘thermal battery’.

Plenary presentation and discussion panel

TITLE

Australia: superpower of the zero emissions global economy

SPEAKER

Ross Garnaut

ABSTRACT

Australia is particularly well positioned for the global energy transition. The country's rich endowments for renewable energy and biomass alternatives to fossil fuels coupled with its complementary economic structure make it the natural home for energy intensive manufacturing in the zero emissions future world economy. As an increasing proportion of global industry make the switch, Australia must learn how to make use of its advantages. How then should Australia move forward to meet its potential?

Professor Ross Garnaut will discuss the difficult global challenges for the new economy and Australia's role in meeting it. It addresses the significant role of policies in unlocking Australia's potential in the energy transition. The discussion will outline how sound policy can, support a zero emissions economy with rising incomes, and Australia to play a positive role in the global transition.

DISCUSSANTS

Tony Wood and Leslie Martin

Professor Garnaut is Professorial Research Fellow in Economics at The University of Melbourne, previously Distinguished Professor of Economics at The Australian National University. Professor Garnaut has had longstanding and successful roles as policy advisor, diplomat and businessman. He was the principal economic adviser to Australian Prime Minister Bob Hawke 1983-1985, and Australian Ambassador to China 1985-1988.

He is the author of a number of influential reports to the Australian Government, including, *The Garnaut Climate Change Review 2008*, and *The Garnaut Review 2011: Australia and the Global Response to Climate Change*.

Professor Garnaut has chaired the boards of major Australian and International companies since 1988, and is President of SIMEC Energy Australia. Professor Garnaut was made Office of the Order of Australia (AO) in 1991 for education and international relations and a Companion of the Order of Australia (AC) in 2007 for climate change and energy.

Keynote speakers

TITLE

Governing the global climate and energy finance revolution

SPEAKER

Christian Downie

ABSTRACT

Since the Paris Agreement in 2015 global attention has turned to the vast amounts of finance that will be required to achieve an energy transition capable of averting the catastrophic consequences of climate change. Indeed, estimates suggest that some $US 7 trillion will be required per year to finance low-carbon infrastructure, renewable energy, energy efficiency and other mitigation measures. While the finance sector has barely begun its journey towards sustainability, globally a number of governance initiatives have commenced that seek to identify institutional and market barriers to green finance, and to enhance the ability of the financial system to mobilize private capital for green investment. As the premier forum on global financial governance, the G20, in conjunction with other international organisations, such as the Financial Stability Board, have been at the centre of recent efforts. This presentation provides an overview of two of these global governance initiatives and considers the implications for finance sectors around the world, including in Australia.

Christian Downie is an Australian Research Council DECRA Fellow in the School of Regulation and Global Governance at the Australian National University. He was previously a Vice Chancellor's Postdoctoral Fellow at the University of New South Wales. Christian has worked as a foreign policy advisor to the Department of the Prime Minister and Cabinet and a climate policy advisor to the Department of Climate Change. Christian holds a PhD in international relations and political science from the Australian National University, and has spent time teaching or researching at the Massachusetts Institute of Technology, the London School of Economics and Political Science and the Balsillie School of International Affairs among others. Christian is the author of more than 20 peer-reviewed journal articles and book chapters. His latest book, Business Battles in the U.S. Energy Sector, was published in 2019.

Keynote speakers

TITLE

Investing in Australia's decarbonisation

SPEAKER

Paul Dowling

ABSTRACT

The Clean Energy Finance Corporation invests across all areas of Australia's economy in order to lower emissions. The CEFC takes an economy-wide view of Australia's emissions, costs of decarbonisation options, and the investable opportunities to maximise investment impact.

The pathways for deep decarbonisation of the electricity, road transport and built environment are reasonably well known. The industry sector's decarbonisation options are less well known, and industry contains several of the so called 'hard-to-abate' sectors. The CEFC has been researching the technologies and investment options for decarbonising industry.

Pathways for net-zero emissions mostly include a requirement for negative emissions. One of the main options in this sector is using the land sector to store carbon, which can be considered in three groups based on the use of the land and the revenue model: carbon-credit projects, forestry, and agriculture. CEFC has been researching the options for financing emissions reductions in the land sector.

Paul Dowling is Associate Director, Investment Research at the Clean Energy Finance Corporation. Paul is a senior energy expert with broad analysis experience across fuels, renewables, energy policy and new technologies. Prior to joining the CEFC, Paul worked for and consulted to Australian and international energy organisations including the UK-based think tank Carbon Tracker Initiative, Origin Energy, Infigen Energy and AGL Energy. Paul has considerable international experience, including roles at the International Energy Agency, working on the World Energy Outlook, and The European Commission's Joint Research Centre. Paul has a Master of Business Administration from the Open University and a Bachelor of Mechanical Engineering from the University of Queensland.

Keynote speakers

TITLE

Rooftop solar penetration and the spillovers to generator efficiency and competition in the Western Australian wholesale electricity market

SPEAKER

Gordon Leslie

Gordon Leslie is an economist with fields of study in industrial organisation and energy economics. He examines firm conduct and responses to policy and regulation changes in many of the world's electricity markets to understand when various market designs, regulatory rules, competition policies and environmental policies are effective in meeting their goals. The primary theme underpinning his research is that environmental and competition policy in energy and electricity markets needs to be developed with a thorough understanding of the existing market structure and physical constraints.

ABSTRACT

The rapid growth in electricity production from solar resources has decreased the production by thermal (fossil fuel) generators. However, there is some concern regarding the "intermittency cost" of renewable generation: thermal generators are often required to take costly actions to start up or ramp production quickly in response to falling solar production when daylight ends or clouds form. This paper examines how the rapid growth in rooftop solar installations in Western Australia impacted the operation of gas-fired power plants in Western Australia. Corresponding to a 5-fold increase in rooftop solar from 2013-2018, we find that the aggregate market-wide heat rate (GJ of thermal energy divided by MWh of electricity production) increased by 5%. This fall in fleet efficiency is due to base load generation with high start-up costs and low marginal costs decreasing their production. Further, rents to generators operating at the sunset peak have increased. Our results suggest that markets will transition toward more flexible thermal technologies as solar penetration increases; this in turn increases the importance of incorporating market mechanisms for assigning the costs of balancing supply and demand at every instant.

Keynote speakers

TITLE

Coal plant exit trajectories for Australia

SPEAKER

Frank Jotzo

Frank Jotzo is Professor at the ANU Crawford School of Public Policy, where he directs the Centre for Climate and Energy Policy. He is a co-director of the Energy Transition Hub, an Australian-German research initiative. As an environmental economist, his research focuses on policy relevant aspects of climate change and energy. Frank is joint editor-in-chief of the journal Climate Policy and a lead author of Intergovernmental Panel on Climate Change 5th and 6th Assessment Reports. He has been involved in various policy research and advisory exercises, including as senior advisor to Australia's Garnaut Climate Change Review, as advisor to governments, and to international organisations.

ABSTRACT

Coal exit in Australia could come faster than expected. Many of Australia's remaining coal power plants are relatively old. Newly built wind and solar plants produce energy at far lower costs than any new coal plant would, and the cost of new renewables including firming may fall to compete with the operating costs of coal plants. We provide a plant-by-plant analysis of the future economics of the coal fired power plants in the National Energy Market under assumptions about a range of cost factors. Our analysis suggests that under many combinations of plausible assumptions, coal plants will become uneconomic long before the end of the technical lifetime of plants. Depending on their ability to command above-cost prices, coal plants might exit much sooner than previous analyses suggested, and exit could be sudden. This suggests the need for a policy and regulatory framework that provides greater predictability of coal plant exit, possibly in the form of a roadmap for closures. This would facilitate replacement investments to come on stream in time, and allow local communities to better prepare for the inevitable economic transition.

Keynote speakers

TITLE

Selective memory of past energy and climate policies

SPEAKER

Heather Lovell

ABSTRACT

This talk examines what happens over time with climate and energy policies, through two case studies of government smart grid programs implemented ten years ago in Australia: *Smart Grid Smart City* and the Victorian Advanced Metering Infrastructure (AMI) Program. What was the early promise of these smart grid initiatives, and how did they fare as they were implemented? And what is their legacy, how are they remembered, and what (if anything) is happening differently now? These questions are perhaps obvious ones, but in the rush to develop new policy it is not that often we take the time to remember, evaluate, and reflect on what went before. This is particularly the case in areas of fast-changing technology such as smart grids, and especially when one of the programs (the Victorian AMI) came to be labelled a policy failure. Scholars are concerned about the loss of institutional memory, and in this short talk I suggest there are also some practical implications arising from neglect of the past.

Professor Heather Lovell is a human geographer with research interests in energy, climate change and the environment. Heather is an Australian Research Council *Future Fellow* (2015-20) at the University of Tasmania, Australia, and has previously held positions at Edinburgh, Durham and Oxford Universities in the UK. Heather has led a number of social science research teams within large interdisciplinary energy projects, including ARENA Consort (2016-19; $2.9M) and IDEAL (2013-17; $3M). She has twenty years experience conducting energy and climate change social research for research funding bodies as well as industry and government, in the UK and Australia.

Keynote speakers

TITLE

Energy policy to help meet the 2030 emissions target

SPEAKER

Tony Wood

ABSTRACT

What role will energy policy play in meeting the 2030 emissions target? Tony Wood will examine various options that might be considered by government, and discuss the interplay with the objectives of lowering electricity prices and providing greater confidence for investors in Australia's power sector.

Tony Wood has led the Grattan Institute's Energy Program since mid-2011. Since then he and his team have delivered 20 major reports on energy and climate change and he has developed a strong profile with governments and industry. From 2009 until mid-2014, he was also Program Director of Clean Energy Projects at the Clinton Foundation, advising governments in the Asia-Pacific region on effective deployment of large-scale, low-emission energy technologies such as solar and CCS.

Prior to these roles, he spent 14 years working at Origin Energy in senior executive roles. In 2008, he was seconded to provide an industry perspective to the first Garnaut review.

In January, 2018 Tony was awarded a Member of the Order of Australia in recognition of his significant service to conservation and the environment, particularly in the areas of energy policy, climate change and sustainability.

Plenary presentation and discussion panel

TITLE

Fossil fuels: Flourishing, finite or finished?

SPEAKER

Peta Ashworth

ABSTRACT

More recently the debate around the role of fossil fuels in the future energy mix – not only in Australia but also for the world – has increased exponentially. Notwithstanding that not all fossil fuels are treated equally, the debate becomes even more complicated when trying to address the need for a "just transition" to a low carbon society. Moving 1 billion people out of energy poverty, while still ensuring we mitigate greenhouse gas emissions is no small challenge. Particularly, given the latest World Energy Council's report (2018) that suggests that based on the number of relatively new coal plants built over the last 10 – 15 years (particularly across Asia) we are essentially locked in to emissions for years to come. However, according to Myles Allen and colleagues, we have already exceeded the world's carbon budget and the only way to justify ongoing use of fossil fuels will be if carbon dioxide is abated through the use of carbon, capture and storage or carbon, capture, utilisation and storage. This talk will address some of the implications arising as a result of this debate. It will present the results from recent survey work investigating the Australian public's attitudes to fossil fuels and other energy technologies and discuss the implications for Australia and its potential to transition to a low carbon energy future.

DISCUSSANTS

Rebecca Colvin and Anna Herring

Peta joined the University of Queensland in April, 2016. As Chair in Sustainable Energy Futures, Peta has responsibility for the Master of Sustainable Energy. She is also tasked with the role of building energy literacy more broadly and continuing her research around public perceptions of climate and energy technologies. Peta is well known for her expertise in the energy field, stakeholder engagement and technology assessment. Peta has been researching public attitudes to climate and energy technologies using large scale surveys and other qualitative methods for the past fifteen years. Her main interest in designing a range of dialogic processes for engaging around complex issues and new science and technology. Previously, Peta conceptualised and led the Science into Society Group within CSIRO's Division of Earth Science and Resource Engineering, which specialised in interdisciplinary research at the interface between science and society. Peta is also a partner in the Horizon 2020 "Responsible Research and Innovation in Practice" project which brings together a unique group of international experts to understand the barriers and drivers to Responsible Research and Innovation.

Keynote speakers

TITLE

LNG: Central to the future of Australia's energy export industry

SPEAKER

Paul Stanwix

Dr. Paul Stanwix is a Senior Lecturer in the School of Engineering at The University of Western Australia (UWA), member of the Fluid Science and Resources group, and researcher with the Australian Centre for LNG Futures. His current research focusses on improving natural gas processing and LNG production by enhancing our ability to detect and understand fluid behaviour at industrial conditions. He received his PhD in Physics from UWA in 2008, after which he was a Postdoctoral Fellow at Harvard University, before returning to UWA in 2011 in the role of Assistant Director for Research at the UWA Centre for Energy.

ABSTRACT

Natural gas is Australia's third largest export commodity, providing reliable and relatively low-emission energy for markets primarily in Japan, China, and South Korea. The distance to these markets means Australia relies upon the production and shipping of Liquefied Natural Gas (LNG). However, the advent of low-cost renewable energy, a desire for carbon-neutral energy by major importers, as well as a rapidly increasing global supply of LNG presents a range of challenges and opportunities for the ongoing growth of Australia's LNG industry. In this talk, I will provide a summary of the research programs at The University of Western Australia and the Australian Centre for LNG Futures which are enabling the continual drive towards more efficient and reliable production of LNG, to maintain Australia's position as a leading LNG exporter. I will also discuss the opportunities for LNG as the world transitions to green-energy, for which LNG is widely expected to play a growing role. In particular, I will provide an overview of the proposed Cooperative Research Centre for Future Energy Exports, which aims to support the development of a world-leading hydrogen export industry by leveraging Australia's existing LNG expertise, capabilities, and infrastructure.

Keynote speakers

TITLE

Transitional fossil fuels strategy: Considering community engagement and policy in the energy transition

SPEAKER

Sara Bice

Sara Bice is Associate 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. Sara is Associate Professor (Special International Guest) at the School of Public Policy and Management, Tsinghua University, Beijing.

Sara is an award-winning author and her latest co-edited book, Public Policy in the Asian Century is available from Palgrave Macmillan.

ABSTRACT

The transition from fossil fuels is a critical strategy to achieve a zero carbon Australia. The uptake of renewables subsidies, the growth of home solar and the emergence of an Australian prosumer/micro-grid market all signal public interest in supporting this aim. At the same time, however, Australians recently re-elected a Government with an overt interest in continuing Australia's fossil fuel industry. Indeed, voting figures suggest that Queenslanders' fear of economic losses due to a declining coal industry under a Labor Government pushed the Coalition to victory.

It is within this environment that policymakers and climate change leaders must consider the role of public understanding and community engagement in the energy transition. Research demonstrates that 'climate change' remains a contentious concept, with doubters holding firmly to climate denialist science, while activists are, well, active. But it is perhaps 'middle Australians' who are most important to consider here.

How can individuals concerned with declining property prices, ageing parents, inflation rates or children's school fees be encouraged to engage with an abstract and long-burning issue like climate change?

How can policymakers promoting the energy transition ease the concerns of individuals who see the end of Australia's coal industry as a direct threat to their jobs, communities and livelihood identities?

Does the energy transition really have a social licence in Australia?

This talk considers these complex but central social considerations influencing the shape and success of policymaking for the energy transition. Drawing on research into social licence to operate, community understanding of energy transitions and social risk profiles, it aims to set out the key social and community considerations necessary to effective transitional policymaking.

Keynote speakers

TITLE

Phasing out coal fired power generation in Australia: Accelerating a just and well managed transition

SPEAKER

John Wiseman

ABSTRACT

A proactive, well planned strategy for accelerating the just and orderly phase out of coal fired power stations is likely to achieve faster GHG emission reductions and better social and economic outcomes than an unplanned, reactive approach. The timetable for closure of coal fired power stations in Australia will probably be shorter than currently assumed given ongoing rapid reductions in renewable energy prices. However closure of coal fired power stations at the speed required to meet GHG emission targets consistent with keeping global temperatures below 1.5 degrees will require proactive policy and strategic leadership which accelerates power station closures; maintains energy security and affordability; strengthens national and regional economic performance and ensures just transitions for workers and communities in coal dependent regions. This presentation will draw on recent learning from Australian and international coal phase-out strategies to clarify key priorities for accelerating the phase out of Australian coal fired power stations, focusing particularly on actions required to achieve just transition outcomes for workers, communities and energy users.

Professor John Wiseman is a Research Fellow with the Melbourne Sustainable Society Institute (MSSI) and the Energy Transition Research Hub, University of Melbourne and a Research Associate with the Centre for Climate Economics and Policy, Crawford School of Public Policy, Australian National University. Previous academic and public policy roles include Deputy Director, MSSI; Foundation Director, McCaughey Centre for Community Wellbeing, Melbourne School of Population and Global Health; and Assistant Director, Policy Development and Research, Victorian Department of Premier and Cabinet. The main focus of his current research is on strategies for accelerating the transition to a just and resilient zero-carbon economy.

Keynote speakers

TITLE

The impact of CO2 injection and storage on water quality in subsurface reservoirs

SPEAKER

Ralf Haese

ABSTRACT

Most of Australia's onshore deep sedimentary basins host low-salinity water; in some instances, prospective CO2 storage reservoirs contain water of drinking or potable water quality. It is therefore important for the community and the regulator to understand the potential impact of CO2 injection and storage on water resources. The principle changes in water composition related to CO2 dissolution and subsequent water-rock reactions have been known for a long time. However, questions relating to the extent of the solute plume, the rate of chemical reactions and the role of CO2 impurities on water quality have only been addressed more recently and results will be presented. Furthermore, the opportunity for a subsurface barrier formation to protect shallow groundwater resources from the influence of CO2 in case of a leak from a deeper storage reservoir will be discussed.

Ralf Haese received his PhD in Earth Sciences from the University of Bremen (Germany) in 1997, spent seven years as a post-doc and research fellow at the University of Utrecht (The Netherlands), and joined Geoscience Australia as a project leader and discipline leader in 2003. In 2013, he joined The University of Melbourne as Chair for Geological Carbon Storage and member of the Peter Cook Centre for CCS Research. In 2017, he was appointed as Director of the Peter Cook Centre. Ralf Haese is a low-temperature geochemist with a focus on the geochemistry of geological carbon storage involving approaches such geochemical engineering, reactive-transport modelling and advanced reservoir characterisation. He teaches Environmental Geosciences to undergraduate students.

Keynote speakers

TITLE

CO2 and brine flows in heterogeneous geologic systems

SPEAKER

Anna Herring

ABSTRACT

As CO2 is injected into a geologic reservoir, it follows tortuous and complex microscopic pathways through granular rock architecture. The geometry and topology of these small-scale CO2 pathways is linked to large-scale flow properties, such as relative permeability and capillary trapping levels, values that are needed to inform reservoir-scale models and operational strategies of CO2 injections. Predicting CO2 distribution is a tricky problem, as it is dependent on many components, including the rock microstructure, the minerals forming and coating the rock grains, the distributions of other fluids already present in the rock, and the conditions of the reservoir and injection (e.g. pressure, temperature, flow rate). Considerable work has been conducted in “model” systems – glass beads, homogenous quarry rocks – to establish links between microscale and reservoir scale properties, and now these need to be tested in real geologic formations targeted for CO2 sequestration. Using high-resolution 3D X-ray tomographic microscopy to visualize flow experiments of CO2 and brine (groundwater analogue) fluid flows in highly heterogeneous and mineralogically complex reservoir sandstones, we examine how CO2 will behave in real geologic settings under reservoir-relevant conditions; and further demonstrate how we can use this information to engineer efficient and secure CO2 injections.

Anna Herring was trained as an environmental engineer, having obtained a B.Sc. from University of Colorado (2010), M.Sc. from Oregon State University (2013), and Ph.D. from Oregon State University (2015); she is currently an ARC DECRA postdoctoral fellow at Australian National University in the Department of Applied Mathematics. Her research focuses on investigating the physics and surface chemistry controls on fluid flows in permeable media, with emphasis on the fate and transport of CO2 during geologic CO2 sequestration.

Keynote speakers

TITLE

Australian carbon capture utilisation and storage: are we there yet?

SPEAKER

Linda Stalker

ABSTRACT

How often has it been said that carbon capture and storage (CCS) has “missed the boat”, is “too expensive”, or other comments in a similar vein? Are these statements factual? By looking back over the last 10 years at the Australian and global CCS scene, a large number of changes and leaps forward have been achieved to advance the research and the commercial deployment of not only carbon capture, but CO2 utilisation as well as storage. Researchers and industry are increasing focus on carbon utilisation, to demonstrate potential development of new products that are based on the abundant supply of CO2 at the end of other processes, while issues of cost, scale and drivers to engage in large scale emissions reduction remain. If we are not there yet, how will we get there?

Linda Stalker is Group Leader in Exploration Geosciences and Science Director for the National Geosequestration Laboratory at CSIRO. An Applied Geologist and Petroleum Geochemist, Linda has worked at Statoil, Norway before joining CSIRO in 2000. Research in gas geochemistry and stable isotopes led to carbon capture and storage research in monitoring and verification using chemical tracers. Science communication has become increasingly important to working in pilot scale and demonstration projects, and Linda has sought better approaches to open science dialogue.

She obtained a BSc. (Hons) in Applied Geology from Strathclyde University, and PhD in Petroleum Geochemistry and CO2 Generation at Newcastle University.

ENERGY USAGE AND DEMAND RESPONSE

Plenary presentation and discussion panel

TITLE

Demand management and the least-cost clean energy transition

SPEAKER

Chris Dunstan

ABSTRACT

While the changing nature of energy supply is front page news, the shift in how energy is used has had a greater impact on global energy trends over the past three decades. Likewise, changes in the energy use through energy efficiency improvements, electrification, smart energy management and demand response are critical to delivering a reliable, affordable and clean energy transition in the years to come

This presentation reviews some of these keys trends and opportunities and offers suggestions on how to better integrate changes in the supply and use of energy in order to deliver a least-cost clean energy transition. It also highlights key research priorities for optimising energy use and demand management.

DISCUSSANTS

Sangeetha Chandra-Shekeran & Phillippa Watson

Dr Chris Dunstan is a Research Director at the Institute for Sustainable Futures at the University of Technology Sydney (UTS).

Chris has been active in Australian clean energy policy, programs and research since 1990. Chris played a key role in developing the NSW Greenhouse Gas Abatement Scheme- the world's first Carbon Emissions Trading Scheme. He was also instrumental in developing Australia's first Demand Management Code of Practice for Electricity Networks and the NSW Government's $200 million Climate Change Fund.

Chris' PhD thesis was entitled: *In the Balance: Electricity, Sustainability and Least Cost Competition.*

Since joining UTS in 2006, Chris' research has focused on decentralized energy, electricity demand management and energy productivity. He has led in the development of the Australian Alliance for Energy Productivity, the Australian Decentralised Energy Roadmap, the Electric Driveway, Network Opportunity Maps and many other research projects.

Chris is the interim Research Director for the proposed Cooperative Research Centre: *Reliable Affordable Clean Energy for 2030.*

Keynote speakers

TITLE

Price discrimination, search, and negotiation in an oligopoly: A field experiment in retail electricity, with David P. Byrne and Jia Sheen Nah

SPEAKER

Leslie Martin

ABSTRACT

In many retail markets, prices are negotiated between consumers and companies. In the electricity market that we study, with competitive retailers, fixed and variable charges vary widely across customers, even among customers with the same retailer, in the same distribution network, at similar levels of usage. This paper proposes an audit-study based approach to identify the sources of price dispersion. We create a call center staffed by actors that call real call centers to obtain rates for fictitious customers with experimentally-assigned combinations of customer characteristics. We find that prices posted on retailer websites only tell part of the story. Firms are willing to reduce their profit margins by 30% for customers who call in and negotiate rates. The best deals are obtained by callers who provide the lowest reference prices. Firms are less willing to negotiate lower prices with new arrivals to the market than with customers looking to switch retailers. Finally, we find no evidence of explicit price discrimination based on government-subsidy status. The incomplete pass-through of government subsidies for vulnerable customers documented by the ACCC can be attributed to lower likelihood to search and lower willingness to accept direct-debit or pay-on-time plans.

Leslie Martin's research lies at the intersection of environmental, energy, and industrial economics and international development. Her research focuses on consumer responses to the availability of smart meter data in markets with retail competition and the interactions between regulation, firms, and environmental outcomes in industrializing countries. She has also conducted a recent evaluation of driver responses to road use charges and is launching a new research project on the environmental impact of clustering manufacturing into special economic zones in rapidly industrializing countries. She has a PhD in Agricultural and Resource Economics from the University of California, Berkeley and a BA in applied math from MIT.

Keynote speakers

TITLE

National Energy Analytics Research program

SPEAKER

Sarea Coates

ABSTRACT

NEAR is a partnership between the Department of the Environment and Energy, the CSIRO and the Australian Energy Market Operator developing world-class capabilities in understanding and planning for the Australian energy system. In a rapidly changing energy market, the NEAR program uses modern data science to collect, integrate and enhance information that describes Australia's modern energy use, and provides it through a tailored web platform to underpin key decision making on energy. The NEAR program will link representative consumers energy patterns with energy sector data to provide a better understanding of the modern Australian energy user. NEAR program research has already delivered a rich collection of data products, including:

> national and regional opportunities for demand response programs

> key drivers of energy consumption for Australian households, and

> the evolution of energy consumption across Australia over the last decade.

NEAR partners are currently working with stakeholders including government, regulators, operators and distributors and researchers to support and drive data innovation needed by industry, researchers and policy makers to secure the best possible energy future for Australia.

Sarea has a broad background leading on Commonwealth and COAG energy policy reform agendas. Currently she is leading new work in energy data and consumer analysis, including the energy Consumer Data Right and the Energy Use Data Model. She has also led: the creation of the National Energy Productivity Plan, demand response, national smart meter roll out, network regulation reforms, wind policy and renewables integration. Her previous background is as a strategy consultant (McKinsey), economist and engineer.

Keynote speakers

TITLE

Mapping energy agency and vulnerability in Victoria's changing energy market

SPEAKER

Sangeetha Chandra-Shekeran

ABSTRACT

Little is known about the differential impacts of the energy transition on consumers across space (inner and sub-urban, periurban, regional towns and rural areas). Our early research findings show that the ability to respond to new stressors around energy pricing and seize market and non-market opportunities is not a straight forward function of income and wealth. Rather it is affected by a range of factors including location, land size, housing stock and prices, and other household characteristics. This presentation shows maps of socio-spatial disadvantage and PV uptake by postcode to enrich the debate about equity and the energy transition.

Dr Sangeetha Chandrashekeran is the Deputy Director of the Melbourne Sustainable Society Institute. She holds a joint position in MSSI and as a lecturer and researcher in the School of Geography, Faculty of Science at the University of Melbourne. She is an economic geographer with a focus on the political economic dimensions of environmental change. Sangeetha's research is motivated by the challenge of deep decarbonisation and the political-economic complexities involved with changing large socio-technical systems. She has focused on the energy sector where she has looked at the evolution of demand management; marketization and social equity and environmental outcomes; metering roll-outs and consumer/citizen benefits. Prior to undertaking her PhD, Sangeetha worked in climate change and energy policy.

Keynote speakers

TITLE

Demand management

SPEAKER

Gerard Ledwich

ABSTRACT

Including variation in customer loads and generation will address many of the issues arising in the power system with the growth of renewables. Concerns include:

a. the loss of inertia leading to frequency regulation problems,

b. reduction of spinning reserve to handle sudden changes in supply,

c. lack of schedulability of renewable generation,

d. rising electricity costs.

With modern communication systems and a one-to-many protocol fast emergency stability problems can be addressed by a fast change of customer load and battery energy export. This addresses concerns ‘a’ and ‘b’. Slower balancing issues can be addressed by a market mechanism which encourages a time shift of loads. This presumes a neighbourhood trading scheme which has the requirements of:

1. Scalability to millions of customers,
2. Low communication and market overheads for each transaction,
3. Reflective of network constraints.

An example of such a scheme will be presented and the incentive for battery ownership will rise addressing concerns ‘c’ and ‘d’.

Gerard Ledwich is a Professor in Electrical Power Engineering at QUT and Fellow of the Institution of Engineers Australia.

He has held positions at University of Queensland, and in the Queensland Electricity Commission and the University of Newcastle.

The current position is Chair in Power Engineering at Queensland University of Technology. His research interests include control systems, power electronics, power systems, condition monitoring and distributed generation.

He has published extensively, and is on the editorial panel of Modern Power and Clean Energy.

Keynote speakers

TITLE

Engaging households towards the Future Grid: A strategy for the sector

SPEAKER

Yolande Strengers

Yolande Strengers is Associate Professor of Digital Society and Technology at Monash University's Faculty of Information Technology, where she leads the energy futures theme in the Emerging Technologies Research Lab. Strengers is a digital sociologist specialising in the effects of emerging energy technologies and demand response programs on people's everyday lives, particularly in the home. Her research is highly applied, and delivered in collaboration with research partners include electricity distribution businesses, consumer advocacy organisations, peak bodies such as Energy Consumers Australia, and the Australian Research Council. She is author of *Smart Energy Technologies in Everyday Life* (2013) and has published widely on energy consumption and demand management in households.

ABSTRACT

The Future Grid is characterised by increasing distributed energy resources and demand response, facilitated by household participation, home batteries and other emerging technologies. In this talk, Strengers will present an electricity sector-wide engagement strategy that was the outcome of the 1-year Future Grid Homes project funded by Energy Consumers Australia. The research involved qualitative research with Australian households and industry stakeholders, and analysed household engagement materials produced by the sector. The findings indicate a range of opportunities and pathways for engaging households towards the Future Grid. The Engagement Strategy highlights the need for differentiated, flexible and inclusive approaches, which are illustrated through a series of experimental program example ideas intended to help put it into practice.

Keynote speakers

TITLE

Demand management solutions: Householder insights from the CONSORT Bruny Island Battery Trial

SPEAKER

Phillipa Watson

ABSTRACT

Electricity demand-management strategies are diversifying beyond a previous (more limited) focus on one-way technical control mechanisms. Network-connected distributed energy resources (DER) have expanded what is possible for demand management from a technical point of view. Additionally, a growing body of research using consumer and social lens(es) is allowing multiple perspectives and richer understandings to be incorporated into the design of demand management systems. The CONSORT Bruny Island Battery Trial (completed March 2019) explored a demand management solution that combined home-based DER, a battery controller and a Network Aware coordination (NAC) platform. Alongside technical tests, this trial also explored user (in this case householder) responses to the installed technology, offering insight into contemporary DER-based demand management solutions from both technical and social perspectives. This presentation relates findings from the CONSORT Battery Trial's social research. Participating householders contributed useful understanding, including about: performance of the installed technology over time; extra support required; tensions in motivations of electricity supply stakeholders and householders; preferred levels of control and involvement; and likely levels of technology acceptance. Findings highlight the importance of considering user perspectives and responses in the design and development of DER-based demand management solutions to ensure high levels of user involvement and acceptance.

Dr Phillipa Watson is a Research Fellow in the School of Technology, Environments and Design (TED) at the University of Tasmania. Phillipa has worked in various roles, in particular in: research (at UQ, CSIRO and UTAS); sustainable building consultancy (at Brisbane City Council and RED sustainability consultants); housing design (through private practice); and the development of sustainable assessment tools for built environment professions (in Brisbane City Council, CSIRO, CRC for Construction Innovation). All her work has sought to support smart and sustainable change for both people and the building/ technologies they use. In her energy related research, Phillipa has sought to understand how people respond to and use technologies, homes and energy; how people adapt to improve energy efficiency; and related issues of energy equity.

Plenary presentation and discussion panel

TITLE

Are Australia's failed electricity reforms redeemable?

SPEAKER

Bruce Mountain

Bruce Mountain is the Director of the Victoria Energy Policy Centre (VEPC) at Victoria University. Bruce's research focusses on the application of economics to electricity industry policy, with a particular focus on the design of markets in the context of rapid decarbonisation, the regulation of network monopolies and the operation of retail energy markets. Bruce's PhD (from Victoria University) was on the political economy of electricity network regulation in Australia. He also has degrees in electrical engineering (from the University of Cape Town) and professional qualification (in England) as an accountant. Much of his career has been at the metaphorical coal-face of energy policy as a consultant and, more recently, as a researcher.

ABSTRACT

Australia's National Electricity Market formally turns 20 this year. The NEM involved privatisation in some areas, radical industry restructuring and the creation of wholesale and retail markets. The impetus for this lay in part in dissatisfaction with the performance of state electricity commissions, in part in broader micro-economic reforms that favoured the creation of markets and private risk-taking, and in part in keeping up with fashions elsewhere. However, 20 years after the creation of the NEM, it is now clear that it has failed to deliver its core policy objectives: lower prices and higher productivity. Failures in wholesale markets, electricity distribution and retailing can be identified. The reasons for those failures are diverse and contested. Candidates include: privatisations focussed on the maximisation of financial proceeds rather than public benefits; inconsistent emission reduction policy; the application of the Competition Principles Agreement in the regulation of monopolies; a failure to anticipate the impact of search and switching costs in retail markets; a failure to recognise the distortions attributable to incumbency; shortfalls in competition policy; wishful thinking on the extent to which co-operative federalism could deliver strong institutions; and finally a disproportionate influence in policy of a normative approach that draws on a narrow reading of neoclassical economics. While the best laid plans of mice and men often go awry, the NEM's failings have almost invariably been at customers' rather than shareholders' expense. Much remains to be done to work out why it went so wrong and how to fix it.

DISCUSSANTS

Tim Nelson and Iain MacGill

Keynote speakers

TITLE

The NEM into the 2020s

SPEAKER

Tim Nelson

Associate Professor Tim Nelson leads the AEMC's Economic Analysis division. Associate Professor Nelson joined the AEMC from his previous position as Chief Economist at AGL, one of Australia's largest energy businesses, where he managed the company's public policy advocacy as well as sustainability and strategy. He is a member of Westpac's Stakeholder Advisory Council and the Grattan Institute's Energy Reference Group. He previously held a number of roles with the NSW Government and the Reserve Bank of Australia. Associate Professor Nelson is an associate professor at Griffith University. He holds a PhD in Economics from the University of New England for which he earned a Chancellor's doctoral research medal.

ABSTRACT

In the NEM (and any electricity market for that matter), spot prices are designed to exert an efficient influence on the behaviour of parties that generate and consume electricity both in operational and investment timeframes. Regional pricing in the NEM was designed around competition at scale with very limited demand flexibility and a small number of generators holding the lion's share of the market, each with a handful of large power stations containing rotating generating units dotted around a strong high voltage transmission network.

While this worked wonderfully for the first decade of the NEM, the last decade has been the first of a multi-decadal transformation of the generation fleet. Despite being in its early stages, this transformation is already testing the price envelope of the NEM's wide design limits – prices designed to avoid overabundance (-$1,000/MWh floor price) and scarcity ($14,500/MWh price cap). In the coming decade and beyond, we envisage a future where the proportion of the existing generating stations connected to the HV network is an ever decreasing proportion of the generation in the power system. The lion's share of generation will be located in thousands of locations around the distribution network and this generation will almost entirely consist of relatively small asynchronous machines.

This presentation will consider what policy responses are required to address this transformation.

Keynote speakers

TITLE

The future NEM – how renewable, how consumer centred, how market oriented?

SPEAKER

Iain MacGill

Dr Iain MacGill is an Associate Professor in the School of Electrical Engineering and Telecommunications at UNSW Australia, and Joint Director (Engineering) for the University's Centre for Energy and Environmental Markets (CEEM). CEEM undertakes interdisciplinary research in the monitoring, analysis and design of energy and environmental markets and their associated policy frameworks, with a particular focus on the Australian National Electricity Market. Iain leads work in two of CEEM's three research areas, *Sustainable Energy Transformation*, including energy futures modelling and renewable energy integration; and *Distributed Energy Systems* including distributed generation, energy efficiency and demand-side participation.

ABSTRACT

The past decade has seen the Australian National Electricity Market (NEM) become considerably more renewable with major deployment of wind and photovoltaics, more distributed and user driven, particularly in terms of rooftop photovoltaics, yet arguably less market oriented, with significant questions regarding the effectiveness of present wholesale and retail market competition. Might we expect these trends to continue and, if yes, how far and fast might they go? Much will depend on the evolution, or perhaps even, revolution, of NEM market design and wider arrangements over the next few years. This presentation will consider a range of possible improvements to NEM design to suitably facilitate its clean energy transition through renewables, flexible resources including more engaged energy users, and a practical balance of market driven versus more centralised decision making. It will also explore opportunities to improve our research tools for assisting in such transition.

Keynote speakers

TITLE

Australia's key energy research challenges - The Market Operator view

SPEAKER

Alex Wonhas

Dr Alex Wonhas leads the System Design and Engineering work at the Australian Energy Market Operator (AEMO). As Australia's energy system has commenced the most profound transformation in a century, the Finkel Review has expanded AEMO's role to designing and implementing Australia's future energy system through the Integrated System Plan (ISP). In addition to the ISP, Alex's team continues to provide vital advice on how to maintain system security and reliability during the transition and supports the system integration of new generators.

Prior to AEMO, Alex was the Managing Director for Energy and Resources at Aurecon, a global engineering firm. He also led CSIRO's Environment, Energy and Resources research. Alex holds a PhD in Theoretical Physics from the University of Cambridge, UK.

ABSTRACT

The Australian Energy Market Operator (AEMO) operates Australia's electricity and gas system. It also coordinates the integration of new generators into the energy system and oversees the high-level design of Australia's future energy system. This role gives AEMO a unique vantage point to identify some of the unique near term research challenges Australia needs to resolve with urgency. This high-level overview presents AEMO's view on key research questions in the areas of:

> Operating, forecasting and simulating a vastly more dynamic and complex energy system,

> Developing and demonstrating new technologies to address growing system security issues to enable the secure integration of large-scale and distributed energy resources,

> Improving markets, regulations and planning activities to maintain affordability, reliability and security for consumers while enabling the transition to a lower emissions systems.

While this overview is focused on the near term challenges AEMO experiences, it recognises there are many more essential or beneficial research questions worthy of scientific exploration.

Keynote speakers

TITLE

Deliberating about new gas markets in Australia: Exploring potential tight and shale gas development with regional stakeholders

SPEAKER

Justine Lacey

Justine Lacey[1], Yuwan Malakar[1], Shelley Rodriguez[1], Anthony Swirepik[2], Andrew Stacey[2] & Rod Dann[2]

Dr Justine Lacey leads CSIRO's Responsible Innovation Initiative; a research program examining the interface between science, technology innovation and the associated ethical, social and legal consequences of new and disruptive science and technologies. This Initiative is aligned with CSIRO's Future Science Platforms, which aim to develop the early stage science that underpins disruptive innovation and that has the potential to reinvent and create new industries for Australia. Prior to this, Justine led a research group of social and economic scientists developing and supporting adaptive solutions for Australian communities and industries. She is trained as a philosopher and her own research has focused on examining the aspects underpinning the minerals industry's social licence to operate, and how this concept is used in other resource management contexts, such as energy, forestry and agriculture.

ABSTRACT

In recent reforms to energy policy, the Australian Government prioritised the development of additional gas resources to meet Australia's current and future demand, including tight and shale gas resources. It is well-established there is a need to respond transparently to community interests and concerns about the potential social and environmental impacts of unconventional gas development, which has been contentious in Australia and around the world. In this context, there is a commitment within the Australian Government's existing $30.4 million Geological and Bioregional Assessment program to not only provide independent scientific advice to governments and regulators, landowners, communities, businesses and industries about the potential environmental impacts of developing these resources but to host a long-term dialogue with key stakeholders in three major basins across the country to fully consider the lived impacts of such developments in the landscape. These dialogues engage with key stakeholders and communities about their views and expectations of gas development within their own regions. They also provide decision-makers with access to an understanding of the needs and expectations of stakeholders and communities that can be considered alongside the scientific and environmental impact assessments. This presentation highlights the role of community and public engagement processes in getting new gas resources into Australian markets.

1 CSIRO Land & Water, Brisbane, Australia

2 Department of the Environment & Energy, Canberra, Australia

Keynote speakers

TITLE

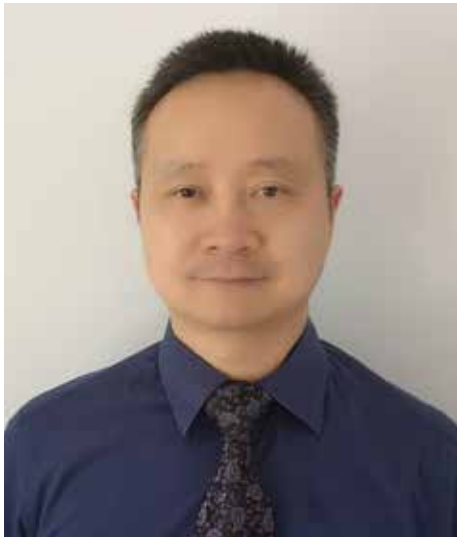
Natural gas pricing transition in East Asia: An Australian perspective

SPEAKER

Xunpeng Shi

ABSTRACT

Natural gas is, arguably, a bridging energy source for the energy transition. While East Asia is the main destination of global LNG trade, natural gas and LNG have not yet formed an independent price in East Asia. Following the North America and Europe, East Asian countries are beginning to establish independent natural gas prices to replace oil linkage. This pricing transition will lead to great changes in the natural gas industry, such as the competition in electricity and natural gas markets, the long-term contract models, and international LNG trade and shipping practice. Since Australia has grown to be the world's largest LNG exporter, what is happening in the East Asian gas market will have profound impact on Australia's LNG export business and domestic market. Roc is a pioneer researcher on East Asian gas pricing transition. He has published 15 peer reviewed journal papers on this topic including in leading journals such as *Energy Economics, Energy Policy and Applied Energy*, and cover issues for Australia, China and East Asia broadly. In this presentation, he will share the progress of research on this topic, and some policy, market, economic and financial issues in Australian, Chinese and the East Asian gas markets.



Xunpeng (Roc) Shi is a Principal Research Fellow at the Australia-China Relations Institute, UTS. He is also an Adjunct Senior Research Fellow at the Energy Studies Institute (ESI), National University of Singapore. He is currently serving as a Senior Advisor to WEC-Global Gas Center, a Member of National Expert Council of APEC Sustainable Energy Center (APSEC), an Associate Editor of *Journal of Modelling in Management* and an editorial board member of *Natural Gas Industry B*. He was President of the "Chinese Economics Society Australia" (2016-2018) and has worked in Australia, Brunei, China, Indonesia and Singapore. His areas of expertise include environmental, energy economics and policy, with a regional focus of Australia, China, ASEAN, and Northeast Asia. His has advised international organizations including ADB, ERIA, GIIGNL, and UN ESCAP. He has published 50+ papers in SCI/SSCI indexed journals. He received his PhD of Economics from the Australian National University in 2009.

Keynote speakers

TITLE

Transformation or transition? The role of gas in the Australian energy market

SPEAKER

Ross Lambie

ABSTRACT

Natural gas has consistently been identified as playing a pivotal role in the transition to a cleaner, more efficient energy system. This is largely due to its lower emissions when compared to other fossil fuels, but is also due to its flexibility to be utilised by different power generators across the merit order. But this transformational role is being challenged in domestic markets, as a result of both domestic and global factors related to natural gas. The partial integration of the domestic Australian east coast gas market to international LNG markets is a primary influencing factor. So too are changes in how natural gas is being traded, as well as international and domestic refinements to emissions estimation methods for natural gas extraction. This presentation will discuss how these developments may explain the shifting expectation for the role of gas in Australia's energy system transformation beyond 2030.

Ross is the Chief Economist and Assistant Secretary of the Economics and Analysis Branch in the Department of the Environment and Energy. Prior to this position, he was General Manager of the Resources and Energy Economics Branch in the Department of Industry, Innovation and Science.

Ross joined the Australian Government in 2013, after spending two years managing the economics team at the ACT Independent Competition and Regulatory Commission. He has almost 10 years' experience as manager of trading teams in the New Zealand Financial Markets.

Ross has a strong academic background in environmental, energy and financial economics. He also holds a PhD in Public Policy and Economics from the Australian National University.

Since 2015, Ross has been an Advisory Board member of the Asia Pacific Energy Research Centre (APERC), and has recently been appointed an Advisory Board member of BehaviourWorks Australia at Monash University.

Plenary presentation and discussion panel

TITLE

Transport and industrial energy

SPEAKER

Michael Brear

ABSTRACT

Australian transport and industry are heavily reliant on the use of oil products and natural gas respectively, and both are comparable in our use to coal on an energy basis. Enhanced sectoral productivity and the displacement of these energy vectors by cleaner alternatives also present particular challenges and opportunities. If we are to achieve deep National decarbonisation in the first half of this century, we must therefore widen our efforts rather than continue our excessive focus on the electricity system.

This talk will first discuss how we use energy in Australian transport and industry. It will then discuss measures for increased productivity and opportunities for fuel substitution in both sectors. This will include a brief review of current efforts by Australian researchers. The talk will then close with suggestions on how good policies for transport and industrial energy might be designed.

DISCUSSANTS

David Viano and Chun Zhu-Li

Michael Brear is the Director of the Melbourne Energy Institute at the University of Melbourne, His own research is collaborative with industry and government on

- the technical, economic and environmental analysis of transport and energy systems;
- systems with reciprocating engines and gas turbines; and
- the combustion of conventional and alternative fuels.

Michael is a Fellow of the Australian Academy of Technology and Engineering and Engineers Australia, and he previously established the University's Master of Energy Systems. Prior to commencing at the University, he worked for ICI Australia (now Orica), then undertook graduate studies at Cambridge University and post-doctoral research at the Massachusetts Institute of Technology.

Keynote speakers

TITLE

Pilot-scale ammonia-to-hydrogen refuelling system for Fuel Cell Electric Vehicles

SPEAKER

David Viano

David Viano is a Research Scientist with CSIRO Energy in Brisbane. David leads a team which investigates H2 production from a range of fossil and renewable resources, a key aspect of which is the development of hydrogen-selective metal membranes. This technology is presently being demonstrated at the pilot-scale for the generation of high-purity H2 from ammonia, work which is central to the establishment of a renewable hydrogen export industry in Australia. David holds a B.E. (Manufacturing and Materials) from the University of Queensland, M.Eng.Sc. from the University of Adelaide and PhD from the University of Queensland.

ABSTRACT

The use of ammonia (NH3) as a hydrogen vector can potentially enable renewable energy export from Australia to markets in Asia and Europe. With a higher hydrogen density than liquid H2, plus existing production and transport infrastructure, and well-developed safety practices and standards, the financial and regulatory barriers to this industry are lower than for liquid H2 transport. The only significant technical barrier which remains, however, is the efficient utilisation of ammonia fuel at the near the point of use, either directly or through the production of H2.

For PEM fuel cell applications, the purity of H2 derived from NH3 is a prime consideration, with ISO14687 stipulating a maximum allowable NH3 content of just 0.1 ppmv. Furthermore, for mobile fuel cells, the limit for N2 is just 100 ppmv. Therefore, if ammonia-derived H2 is intended for use in a fuel cell electric vehicle, extraction of high purity H2 from the decomposed NH3 is essential.

Metal membranes show particular promise for this application as they combine infinite H2 selectivity (i.e., a 100% pure H2 product, assuming a defect-free membrane), high temperature operation (comparable to that required for NH3 decomposition) and tolerance to NH3. CSIRO has recently demonstrated a pilot-scale ammonia-to-hydrogen system, incorporating an ammonia decomposition stage with a subsequent membrane-based hydrogen purification stage, at a rate of several kilograms of H2 per day. Through partnerships with an industrial gas producer and two Fuel Cell Electric Vehicle (FCEV) manufacturers, the resulting H2 has been compressed and dispensed into FCEVs. System design, materials, performance and strategies for scale-up and demonstration will be discussed.

Keynote speakers

TITLE

Consumer behaviour and preferences in the face of new transport technologies: now and in the future

SPEAKER

Jake Whitehead

ABSTRACT

The advent of new transport technologies, like shared, automated and electric vehicles, have spurred public discussion around the wider suitability of these vehicles to meet current mobility needs. In this presentation, I explore the preferences of Australian households towards these new technologies, and provide insight into how electric vehicle owners are already using and charging their vehicles in Australia. Building on this evidence, I explore the future implications of these preferences and behaviours, particularly for governments and transport energy providers, including electricity utilities.

Dr Jake Whitehead holds two PhDs in Transport Science and Engineering, is Secretariat of the Australia and New Zealand Clean Transport Academic Partnership (CTAP), and a member of the International Electric Vehicle Policy Council.

Jake's research primarily focuses on the costs, benefits, opportunities and risks of clean transport technologies, as well as understanding the impacts of government policies on supporting and managing the uptake of these innovations. More recently, Jake has been focussing on the synergies between clean transport and energy systems, in particular through the rollout of electric vehicle-to-grid systems, as well as the effectiveness of different transport technology pathways on reaching global emission reduction targets.

Jake works closely with governments and businesses around Australia to advise on sustainable transport policies. These efforts have included co-ordinating the development of Australia's most comprehensive electric vehicle strategy.

Keynote speakers

TITLE

Next generation vehicles - the state of play

SPEAKER

Llewelyn Hughes

ABSTRACT

Governments apply a mix of policy instruments to promote electric vehicles (PHEV, BEV, FCEV). In this presentation I introduce the range of public policies supporting the research, development, and deployment of electric vehicles, and consider the extent to which policy instruments applied by governments are technology neutral across electric vehicle technologies. Data from a number of country case-studies are introduced.

Llewelyn is Associate Dean for Research at the College of Asia & the Pacific, Australian National University, and an Associate Professor at the ANU's Crawford School of Public Policy. In his academic work Llewelyn is interested in how public policies affect, and are affected by, energy markets. He is currently investigating how and why energy policies are changing in response to the problem of climate change, with a particular focus on the Asia-Pacific region. An ongoing project examines how the rise of Global Value Chains affect the ability of governments to promote green growth industries. In addition to his academic work, Llewelyn assists companies in the energy and environmental sectors navigate regulatory issues in Japan. He received a Ph.D. from the Massachusetts Institute of Technology (MIT), and holds a Masters' degree from the University of Tokyo.

Keynote speakers

TITLE

Cat-HTR™ hydrothermal valorisation of bio- and plastics wastes to fuels and chemicals

SPEAKER

Thomas Maschmeyer

ABSTRACT

Our responses to the current global challenges of climate change, resource scarcity and overpopulation will have ramifications well beyond our life-times. Indeed, the world is standing at the threshold of energy and resources revolutions. At current rates of resource usage, a world population operating with Western standards of living would require between 4 - 6 planets. Clearly, this is untenable and, from a chemical viewpoint, the inherent challenges can only be met by devising strategies for waste reduction and re-use, by optimising power generation and utilisation as well as by increasing the sustainable use of renewable resources.

New paradigms must be found. Fundamental breakthroughs in our understanding of processes at the nanoscale, e.g. in catalysis or energy storage materials, can provide some of the enabling scientific and technological underpinnings for such paradigm shifts.

Some fundamental insights, underpinning commercialisation activities in the renewable fuels space, when using waste biomass or end-of-life mixed plastics will be discussed. These will cover general strategy, chemical breakdown and feedstock and conversion to synthetic oils as well as their upgrading to finished fuel products.

Thomas is Professor of Chemistry at the University of Sydney. He was elected youngest Foreign Member of the Academia Europea, and holds Fellowships of the Australian Academy of Sciences, the Australian Academy of Technological Sciences and Engineering, the Royal Australian Chemical Institute and the Royal Society of NSW.

He is Founding Chairman of *Gelion Technologies* (batteries), co-founder of *Licella Holdings* (bio- and plastic waste conversions) and of *Avantium* (bio-plastics, high-speed experimentation).

He published 320+ items (H-Index 54), including 26 patents. He serves on the editorial/advisory boards of ten international journals and received many awards, including the Eureka Prize for Leadership in Innovation and Science (2018) – Australia's "Science Oscar"; the RACI R. K. Murphy Medal for Industrial Chemistry (2018); the NSW Science & Engineering Award for Renewable Energy Innovation (2013), the RACI Weickhardt Medal for Economic Contributions (2012); the RACI Applied Research Award (2011) and the Le Févre Prize of the Australian Academy of Sciences (2007).

Keynote speakers

TITLE

Hydrogen storage and applications

SPEAKER

Yun Liu

ABSTRACT

Hydrogen is regarded as the most promising source of clean and highly efficient energy, powering the future society. One of the key technologies for utilising hydrogen energy is to find a solution to store, transport and distribute the hydrogen in a safe and controllable manner, whilst it is inexpensive and easily enlargeable in production scale. In this talk, I will, from the technological point of view, present my perspective to the safety issues of hydrogen energy, and compare the pros and cons of currently existing hydrogen storage technologies. I will particularly focus my discussion on the liquid organic hydrogen storage – a technology that allows storing the hydrogen safely at ambient environment. Based on the characters of hydrogen generation, storage and conversion, I will review various hydrogen applications and discuss the potential hydrogen industry model in the future.

Professor Yun Liu is a graduate of the Xian Jiaotong University, China with her BSc, MSc and PhD degree. She held a position at the National Institute of Advanced Industrial Science and Technology (AIST), Japan (1998-2001). She joined the Research School of Chemistry, the Australian National University in 2001 initially as a postdoctoral fellow and was promoted to Professor in 2015. She has published extensively in the fields of advanced materials. Her fundamental research in materials chemistry and applied physics is closely associated with applied research on electronic/electrical technology, energy and environment, e.g. novel catalysts' design and development for hydrogen generation and storage.

Yun has received not only innovative awards but also prestigious fellowships, such as the AIST (1998-1999) and STA Fellow (1999-2001) in Japan, and ARC QEII (2006-2010) and Future Fellow (2011-2015) in Australia. She is a Fellow of the Australian Institute of Physics (FAIP) and Member of RACI, SCANZ, MA, ANBUG, AES and IEEE.

Keynote speakers

TITLE

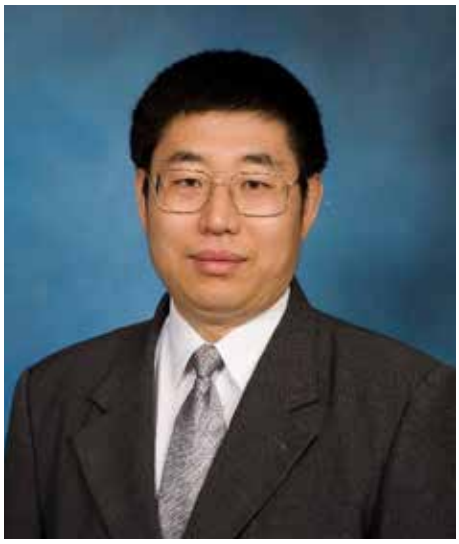
Negative-emission bio-based circular economy

SPEAKER

Chun-Zhu Li

ABSTRACT

Biomass is the only renewable that can be used directly to generate green base-load electricity and to produce liquid fuels, chemicals, solid fuels, reductants and biocarbon materials. Biomass is also the only renewable that can achieve negative emissions by returning biochar into the soil. The net result is the safe and permanent sequestration of atmospheric CO2 into the soil. The biochar will also greatly improve the soil productivity, thereby ensuring the sustainability of our agriculture and forestry. A modern bioenergy industry will therefore establish a negative-emission bio-based circular economy where the sequestration of atmospheric CO2 is achieved simultaneously with the enhanced production of food, fibre, wood and other natural products as well as the production of green energy, liquid fuels, solid fuels and biocarbon materials. The presentation will give an overview of recent advances in the fundamental research and technology development in the area of Bioenergy Science and Engineering in Curtin University in partnership with Renergi Pty Ltd.



Professor Chun-Zhu Li obtained his PhD in Chemical Engineering from Imperial College London in 1993. After postdoctoral experience, he joined Monash University in 1996 where he served as a Lecturer, Senior Lecturer, Reader and Professor. Professor Li moved to Curtin University in January 2009 to be the Founding Director of Fuels and Energy Technology Institute (initially known as Curtin Centre for Advanced Energy Science and Engineering). Professor Li has co-authored more than 300 papers in journals and conference proceedings. He has also edited a book, *Advances in the Science of Victorian Brown Coal*, and co-authored three chapters in the book. He is a John Curtin Distinguished Professor. He is one of the Most Cited Researchers in Energy Science and Engineering. He is the Editor-in-Chief of *Fuel Processing Technology*. He is the Australian Director of the Australia-China Joint Research Centre for Energy and the Australia-India Joint Research Centre for Coal and Energy Technology. The research work he led in the area of Bioenergy Science and Engineering has resulted in the formation of a spin-off company Renergi Pty Ltd.

Plenary presentation and discussion panel

TITLE

Managing energy systems with high penetration renewable and distributed energy resources

SPEAKER

Lachlan Blackhall

Dr Lachlan Blackhall is Entrepreneurial Fellow and Head, Battery Storage and Grid Integration Program at The Australian National University in Canberra, Australia. Dr Blackhall has 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. Dr Blackhall holds a BE, BSc and a PhD in engineering and applied mathematics, is a Senior Member of the Institute of Electrical and Electronics Engineers and a fellow of the Australian Academy of Technology and Engineering (ATSE).

ABSTRACT

Australia is in the midst of an energy revolution and by 2040 over 75% of Australia's electricity system capacity will be provided by renewable and distributed energy resources. To benefit from these significant changes, we need to understand how we can continue to operate a secure, reliable and efficient electricity system whilst delivering value to energy markets, electricity network operators and utilities, electricity retailers and both residential and industrial energy consumers. In this session, we will discuss the trends for Renewable and Distributed Energy Resources in Australia and globally. We will also explore the technology, policy, projects and initiatives that are already underway that will underpin their integration.

DISCUSSANTS

Ian Hiskens and Maria Vrakopoulou

Keynote speakers

TITLE

Optimal power flow reformulations facilitating the secure integration of renewables

SPEAKER

Maria Vrakopoulou

Dr. Maria Vrakopoulou is a lecturer in power and energy systems at The University of Melbourne. She received her diploma in Electrical and Computer Engineering from the University of Patras, Greece in 2008, and her Ph.D. degree from the Department of Electrical Engineering and Information Technology, at ETH Zurich, Switzerland in December 2013. Dr. Vrakopoulou pursued her research as a post-doc in the University of Michigan, Ann Arbor, MI, in the University of California, Berkeley, CA, USA, and the Automatic Control Laboratory in the Department of Electrical Engineering and Information Technology, ETH Zurich, Switzerland as a Marie Curie post-doctoral fellow.

ABSTRACT

The increasing penetration of renewables and distributed energy resources across the power system is increasing system uncertainty and hence operational challenges are introduced. The transmission system operator faces every day a decision-making problem with regards to many controllable set-points in the network. The decision-making algorithms could incorporate the introduced uncertainty in a robust way but this will most likely result in a very expensive system operation. On the other hand, by using heuristically chosen certain scenario cases of the uncertainty, solutions may not ensure the reliability of the system. In this context, chance constrained OPF reformulations of transmission system operational problems can prove an effective approach to achieve an optimal cost and a desirable reliability. In particular, to solve the chance-constrained DC and AC OPF problems, the talk will discuss the use of data-based optimization techniques that do not rely on the underlying distribution of the uncertainty and provide a solution that comes along with probabilistic guarantees. Furthermore, policy-based control of different network components will be introduced to achieve improvement in the operational costs but also make the scenario-based optimization applicable. Ultimately, since certain components may provide power balancing reserves (e.g. generators, loads) and other only power flow control (e.g. HVDC lines), the talk will show that the proposed framework will offer a solution that quantifies the system reliability probabilistically while decreasing the operating costs by taking advantage of the potential flexibility of the network.

Keynote speakers

TITLE

Unlocking bottom-up services: Orchestrating DER

SPEAKER

Nando Ochoa

Luis (Nando) Ochoa is Professor of Smart Grids and Power Systems at The University of Melbourne, Australia and part-time Professor of Smart Grids at The University of Manchester, UK. His expertise in network integration of distributed energy resources (DER) and his extensive portfolio of industrial and academic projects have led to 150+ publications, 60+ technical reports, and two patents, one filed by Psymetrix Ltd (now part of GE) and one filed by The University of Melbourne. Prof Ochoa is an IEEE PES Distinguished Lecturer and is also Editorial Board Member of the IEEE Power and Energy Magazine. Prof Ochoa is an IEEE Senior Member since 2012. He holds a Bachelor's degree in Mechanical and Electrical Engineering from UNI (Peru), and a Research MSc and a PhD in Electrical Power Engineering, both from UNESP Ilha Solteira (Brazil).

ABSTRACT

More and more services procured by AEMO are bottom-up services, i.e., they come from the distribution network, from customers with distributed energy resources (DER). With residential batteries becoming more popular, this trend is expected to increase further. However, currently, distribution networks are assumed to be fully capable of dealing with the resulting time-varying power flows which can lead to voltage and thermal limit violations. This talk will discuss the role of the Optimal Power Flow (OPF) as a state-of-the-art decision-making engine tailored for large-scale unbalanced distribution networks that can be used in near real-time to truly orchestrate DER by incorporating network constraints and helping with the adequate procurement of bottom-up services. A real Australian 22kV feeder with realistically modelled low voltage networks and 4,500+ households is used as a case study. Results demonstrate the importance of ensuring distribution network integrity and the fact that DER orchestration can unlock large volumes of bottom-up services compared to the use of the static 5kW export limit (per phase) adopted in Australia.

Keynote speakers

TITLE

Optimization applications in power system analysis and control

SPEAKER

Ian Hiskens

ABSTRACT

Power system analysis builds on the so-called power flow equations which describe the relationship between voltages and power injections across large-scale electrical networks. A variety of problems arise in power system planning and operations which can be formulated as optimization problems that incorporate the power flow equations. Unfortunately such problems are non-convex, so ensuring global optimality is challenging. The talk will provide an overview of the optimal power flow (OPF) problem and applications, and will discuss various approximations and relaxations that have been developed for addressing OPF non-convexity. At the other end of the power system scale, coordination of loads, such as electric vehicle charging, can be formulated as centralized optimization problems. However, centralized control faces potential obstacles such as consumer privacy concerns. The talk will present decentralized coordination schemes that offer individual decision-making yet yield the centralized solution.

Ian A. Hiskens is the Vennema Professor of Engineering in the Department of Electrical Engineering and Computer Science, University of Michigan, Ann Arbor. He has held prior appointments in the Queensland electricity supply industry, and various universities in Australia and the United States. His research interests lie at the intersection of power system analysis and systems theory, with recent activity focused largely on integration of renewable generation and controllable loads. Dr. Hiskens is involved in numerous IEEE activities in the Power and Energy Society, Control Systems Society, Circuits and Systems Society, and Smart Grid Initiative, and has served as VP-Finance of the IEEE Systems Council. He is a Fellow of IEEE, a Fellow of Engineers Australia and a Chartered Professional Engineer in Australia.

Keynote speakers

TITLE

Micro-synchrophasors: Enabling scalable solar PV generation in Australian distribution grids

SPEAKER

Elizabeth Ratnam

ABSTRACT

The recent rapid growth of distributed energy resources (DER), including solar PV and battery storage, has introduced numerous challenges for the secure, reliable, and efficient operation of the electricity system, particularly in the distribution networks where DER is primarily being installed. Such challenges and opportunities have prompted the development of sensors such as micro-Phasor Measurement Units (micro-PMU) that provide unprecedented observability into the operation of the low and medium voltage distribution networks. In this talk we will introduce the micro-PMU and we will provide an overview of the research enabled by the device. In particular, we will introduce research underway on a highly innovative framework termed phasor-based control (PBC) to enable greater than 100% solar PV integration in the distribution grid.

Dr Ratnam earned the BEng (Hons I) degree in Electrical Engineering in 2006, and the PhD degree in Electrical Engineering in 2016, all from the University of Newcastle, Australia. She subsequently held postdoctoral research positions with the Center for Energy Research at the University of California San Diego, and at the University of California Berkeley in the California Institute for Energy and Environment. During 2001–2012 she held various positions at Ausgrid, a utility that operates one of the largest electricity distribution networks in Australia. Dr Ratnam currently holds a Future Engineering Research Leader (FERL) Fellowship from the Australian National University (ANU) and she joined the Research School of Engineering at ANU as a research fellow and lecturer in 2018. Her research interests are in developing new and revolutionary approaches to control distribution networks with a strong focus on creating a carbon neutral power grid.

Keynote speakers

TITLE

Is the NEM fit for distributed energy?

SPEAKER

Iain MacGill

ABSTRACT

Consumers are transitioning fast towards a distributed future - certainly in terms of PV uptake - but there is no clear path towards arrangements to integrate distributed energy technologies appropriately. Key questions remain around the appropriateness of network regulation and incentive structures, and approaches to incentivise or control operation of consumer equipment, while the retail interface is already failing to deliver for consumers. Distributed energy "orchestration" promises more efficient electricity industry outcomes and improved integration of variable renewables, but while visibility is required for managing DER consumers are increasingly concerned about privacy, seem to be seeking greater energy autonomy, and there is no clear social license to automate. This presentation will review the potential, challenges and opportunities of distributed energy resources, introduce some of CEEM's open-source modelling tools for assessing outcomes for distributed energy under different arrangements, and consider possible reform pathways for distributed energy integration in the NEM.

Dr Iain MacGill is an Associate Professor in the School of Electrical Engineering and Telecommunications at UNSW Australia, and Joint Director (Engineering) for the University's Centre for Energy and Environmental Markets (CEEM). CEEM undertakes interdisciplinary research in the monitoring, analysis and design of energy and environmental markets and their associated policy frameworks, with a particular focus on the Australian National Electricity Market. Iain leads work in two of CEEM's three research areas, *Sustainable Energy Transformation*, including energy futures modelling and renewable energy integration; and *Distributed Energy Systems* including distributed generation, energy efficiency and demand-side participation.

Keynote speakers

TITLE

Future grid scenario analysis

SPEAKER

Gregor Verbic

Gregor Verbič received the B.Sc., M.Sc., and Ph.D. degrees in electrical engineering from the University of Ljubljana, Ljubljana, Slovenia, in 1995, 2000, and 2003, respectively. In 2005, he was a NATO-NSERC Postdoctoral Fellow with the University of Waterloo, Waterloo, ON, Canada. Since 2010, he has been with the School of Electrical and Information Engineering, The University of Sydney, Sydney, NSW, Australia. His expertise is in power system operation, stability and control, and electricity markets. His current research interests include grid and market integration of renewable energies and distributed energy resources, future grid modelling and scenario analysis, wide-area coordination of distributed energy resources, and demand response. He was a recipient of the IEEE Power and Energy Society Prize Paper Award in 2006. He is an Associate Editor of the IEEE Transactions on Smart Grid.

ABSTRACT

We expect that the power systems of the future will be significantly different from today's, especially due to the increasing penetration of renewable energy sources, storage systems, and price-responsive users, leading to large uncertainty and complexity. In conventional power system planning it was sufficient to analyse only a selected number of the most critical scenarios, which provided critical operating information for stability analysis. In future grid planning, on the other hand, a time-series scanning is required because "cherry-picking" critical operating conditions upfront is impossible due to the constantly varying operating conditions. To account for a wide range of possible future evolutions, this talk will discuss a scenario-based scanning approach used to evaluate the system stability along possible evolution pathways towards high renewable future grids. The simulation platform encompasses market simulation, load flow calculation and stability assessment altogether. As a case study, the talk will present results of frequency stability analysis, and discuss the impact of grid strength, location of inertia and level of prosumers on the frequency performance of the future grid, which enables us to address the underlying stability issues of future grids.

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ORGANIC REDOX FLOW BATTERIES – Quinolinequinones as a case study (Battery Storage)

Rohan Borah[1*] Kristiana Santoso[2†] Mattie Timmer[2†] and Thomas Nann[1*]

[1] School of Mathematical and Physical Sciences, University of Newcastle, Australia

[2] School of Chemical and Physical Sciences, Victoria University of Wellington, New Zealand

The energy crisis scenario of today and the near future presents challenges on several fronts, but the storage of excess energy is perhaps the most pressing. While renewable sources like solar and wind have the potential to alleviate the situation, their intermittency is still a major drawback. One needs large scale, reliable energy storage technologies that can be made available at remarkably low costs to envision a successful renewable energy based grid.

Redox flow batteries (RFBs) are such devices, which can be configured with cheap raw materials and can be scaled up to GWhs of storage capacities with minimal cost implications. While the conventional RFBs are based on metal ion based active materials such as Vanadium, their popularity is stunted by high costs, mediocre performance and safety concerns from the corrosive electrolytes used.

Organic RFBs on the other hand are based on redox active organic molecules (ROMs) which are made of abundant elements and hence involve low costs of acquisition. However, these ROMs need careful screening for parameters such as redox potential, solubility and electrochemical stability and eventually cost of mass production. This work hereby elaborates the working principle of an RFB focusing on challenges and strategies for organic RFB development. Quinones have been identified as a promising class of ROMs for organic RFBs. Quinoline quinones a sub class of these ROMs have been taken as a case study here to emphasise on the issues and advantages involved with organic RFB research.

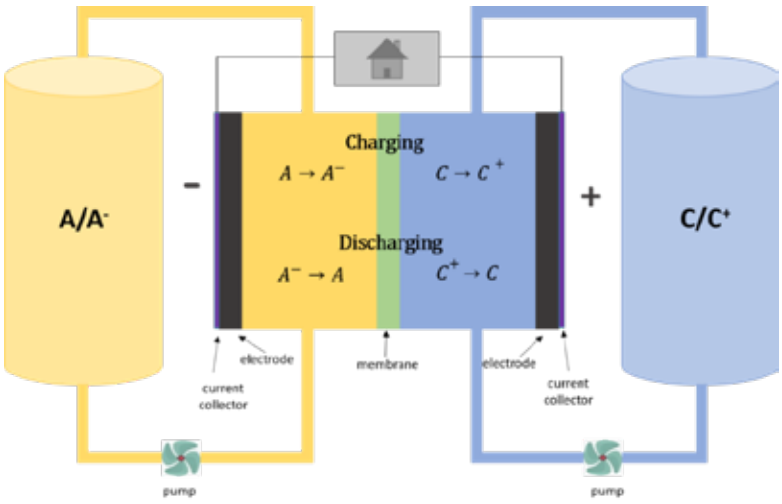

Figure 1: A Schematic representation of a Redox flow battery.

The State-of-Energy-Research Conference 2019 74

FALSE DATA INJECTION ATTACKS VS DEMAND RESPONSE
(Demand Response)

T. T. Dayaratne, A. Liebman, C. Rudolph and M. Salehi
Faculty of IT, Monash University Melbourne, Australia

Smart Grids (SGs) with Advanced Metering Infrastructure (AMI) can be used to enhance the efficiency of Demand Response (DR) schemes, which are programs designed by utility companies (UCs) that drive consumers to change their consumption patterns and better manage their demand with financial incentives. Commonly considered financial incentives include Real-Time Pricing (RTP), Day Ahead Pricing (DAP) and Time of Use (ToU) [1]. DR programs increase the efficiency of electricity grids and help UCs to maintain the grid reliability at a lower cost. These programs allow consumers to make more informed decisions about their usages and reduce their costs through reducing their peak demands, which in turns reduce the overall peak demand, helping UCs to better utilize the existing grid infrastructure, obtain more accurate demand forecast and reduce the need for increasing the reserve generation capacity for future. Users need to make rational decision to achieve the expected results rather than being passive participants in most of the DR systems. However, manually responding to the periodically (possibly every half an hour) changing incentive/pricing signal(s) to actively participate in DR systems is highly inconvenient to a user. Therefore, researchers have proposed distributed DR systems which use the Smart Meters (SMs) and Home Energy Management Systems (HEMSs) to assist consumers with deciding the best time for consuming electricity. These systems obtain information from the UCs and schedule devices automatically for consumers in a way that satisfies consumption requirements and preferences of all customers and reduce their overall costs and the total peak demand [2].

Preserving the data integrity of DR schemes can guarantee the intended benefits for both users and UCs. Therefore, data integrity is an indispensable criterion in such distributed DR systems. However, due to the distributed nature of these DR schemes, where active user participation is essential, there is no guarantee that all users act honestly and truthfully. Financial advantages that can be received by enacted against the standards/ rules of these systems can motivate individuals/groups to inject false data into these systems. These False Data Injection Attacks (FDIAs) can induce incorrect or sub-optimal power flows, excessive or insufficient generation, financial losses, and inconvenience for the users. The gradual adaptation of SGs and distributed DR systems will increase the risk of violating data integrity in the systems. Thus, addressing these security concerns is essential to have more reliable systems in the future.

Despite the research on various security aspects of SG, comparatively less amount of work has focused on how distributed DR schemes in the consumer market are get affected or how stable distributed DR schemes are against FDIAs. Additionally, there is very little literature on how to develop an FDIA detection technique without compromising user privacy. In this research, we have developed and evaluate the impact of different types of data integrity attacks that an adversary can execute on distributed DR schemes. Our experimental results show how a small percentage of overall demand increase can lead to a significant cost reduction for the adversary. Based on our results, we have also developed a model to emphasize the significance of this type of false data injection attacks on general distributed DR schemes orthogonal to the optimization algorithm that a DR scheme use or orthogonal to the number of users in the system. We expect to develop a reliable and accurate detection technique without raising privacy issues which can be used detect FDIAs in an inherently chaotic electricity consumption nature.

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* Contact email:Thusitha.dayaratne@monash.edu
† Group URL:

Impact of Perovskite Solar Cell Degradation on Long-Term Performance of Perovskite/Silicon Tandem Modules (Solar renewable electricity generation)

M. Ernst[1*], J. Qian[1], N. Wu[1] and A. Blakers[1]

[1] Research School of Electrical, Energy and Materials Engineering, Australian National University, Canberra, ACT 2600, Australia

Metal halide perovskite (PSK) solar cells are promising candidates for high-efficiency Si based tandem solar cells and the stability of PSK solar cells is currently rapidly improving. Crucial for the economic viability of PSK/Si tandem devices is the combined degradation rate, which depends on the device configuration, the individual degradation rates of PSK and Si solar cells, and degradation type.

We experimentally determine the electrical and optical PSK cell degradation characteristics and study the long-term performance and economic viability of two and four-terminal (2T and 4T) PSK/Si tandem modules [1].

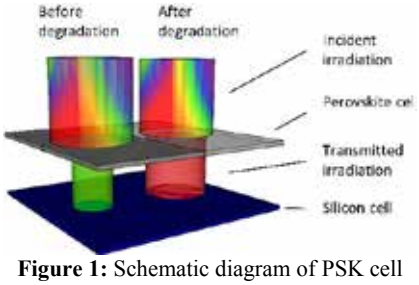

Figure 1: Schematic diagram of PSK cell optical degradation that leads to increased light transmitted to a Si bottom cell.

We investigate the impact of two critical issues involved in the combined degradation mechanism of PSK/Si tandem cells: (1) 2T tandem cells are commonly optimized by matching the maximum power current of both sub-cells to minimize current mismatch losses. However, different electrical degradation rates of the sub-cells can cause an increasing current mismatch and consequently a decrease in tandem efficiency. (2) Change in optical properties of the PSK top cell as illustrated in Fig. 1 due to degradation affecting the transmitted light to the bottom cell may cause increase of the current at the silicon cells. Such current gain could have different effects depending on the cell configuration.

Our PSK cell degradation experiments reveal that the degradation of our PSK cells is dominated by *FF* and I_{SC} degradation with negligible decrease in V_{OC}. We also observe an increase in the transmission of the PSK film after degradation. Based on the experimental results, we estimate the maximum permissible annual degradation rates of PSK top cells in 2T and 4T tandem modules to comply with an industry-typical performance warranty of 80% of the original value after 25 years.

Using the measured PSK cell degradation characteristics, we determine that to maintain 80% of the initial power in a tandem module after 25 years, the maximum permissible perovskite top cell degradation rates are 0.9%/year and 1.3%/year in 2T and 4T configurations as shown in Fig. 2. We project that a future PSK/Si tandem module can produce over 10% more lifetime energy than a 23.3% efficient single-junction Si module assuming a tandem cell efficiency of 28% with a modest PSK cell degradation rate of 2%/year. Furthermore, we estimate the LCOE for 2T and 4T tandem modules. Assuming a PSK cell degradation rate of 2%/year and 50% additional cost for the tandem structure compared to single-junction modules, we find that tandem module efficiencies of 28.7% and 27.6% enable the economic viability of 2T and 4T PSK/Si tandem modules.

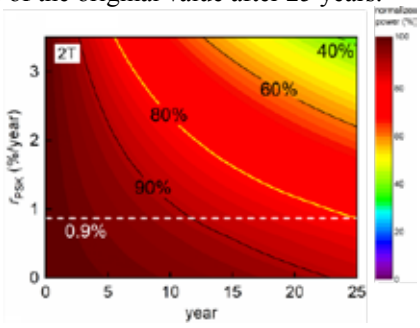

Figure 2. Normalized 2T tandem module power impacted by varying r_{PSK} over 25 years. The dashed lines represent the permissible degradation rate consistent with 80% relative end-of-life performance.

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* Contact email: marco.ernst@anu.edu.au

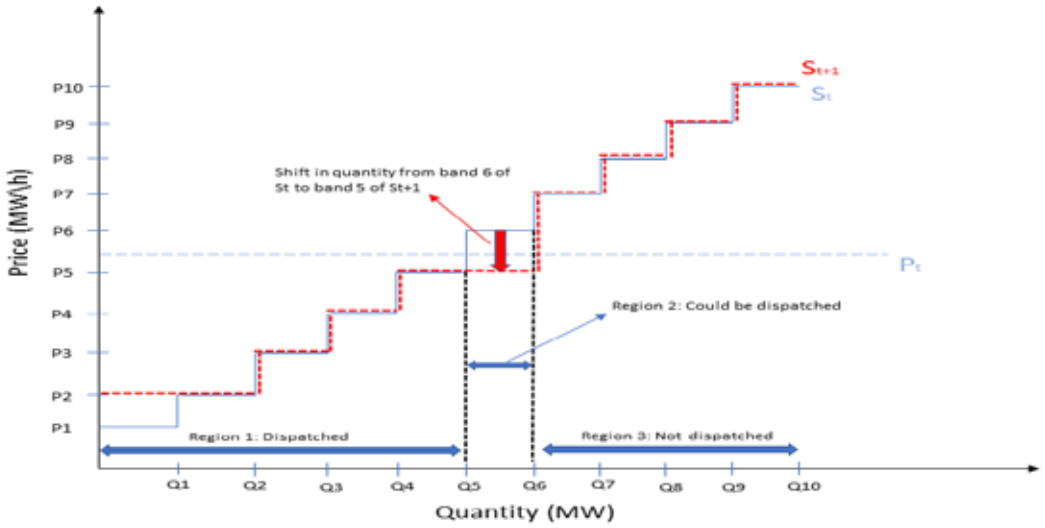
Strategic Rebidding Behaviour: Driving factors in Australian National Electricity Market
(Conference Theme: Energy Economics and Finance)

Ali Ghahremanlou[1*], Clinton Levitt[2*], Harrison Lovell[3*]

[*]Tasmanian School of Business and Economics, University of Tasmania

This paper investigates how the flow of information in Australian National Electricity Market (NEM) provides an incentive for the electricity generating firms to behave strategically. We examine the information disclosed to the generators in real-time at each five-minute auction intervals to see how generators restate their initial offer based on the new information to influence the spot prices. Utilizing a high frequency dataset of three years from 2015 to 2017 provided by the Australian Electricity Market Operator (AEMO) which consists of the intra-day supply bids of each generator, we demonstrate that firms actively respond to the market information by shifting their supply curves within each thirty-minute trading intervals.

Studying each generator's bidding behaviour in the state of New South Wales through a Fixed Effect model, we observe that generators react not to the five-minute dispatch prices but to the difference between the five-minute dispatch prices and the price at which the generator is dispatched. Accordingly, generators move quantities through the rebidding mechanism from the higher part of their supply offer (like the following plot) which carries a higher price to the lower parts which has lower prices and vice-versa depending on what time of the day generator is operating in. The key implications of our results are that firstly, generators have no incentive to reveal their true marginal cost and secondly, the upcoming market redesign in July 2021 which would be a move to five-minute settlement from the current thirty-minute settlement may not be as effective as it is expected to be since generators will be still gaining the same set of information as before to maintain their strategic behaviour. The consequences of such strategic behaviour have been recent high price spikes. This result is consistent with the report by Australian Electricity Market Commission (AEMC) in 2015 that firms take advantage of the current market design as it provides the firms with incentives to generate financial incentives.



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* Contact email: Ali.Ghahremanlou@utas.edu.au

* Group URL: https://www.utas.edu.au/arts-law-education/research/future-energy

A study of how residential battery storage impacts peak electricity demand in summer versus winter in Canberra, Australia (Demand Response)

Lin.Guo, Bjorn. Sturmberg and Marnie.Shaw [1*]

[1] The Battery Storage and Grid Integration Program, Research School of Electrical, Energy and Materials Engineering, ANU, Canberra, Australia

The Next Generation Energy Storage Program (NextGen) was founded by the ACT government in Canberra from 2016 and is one of the largest roll-outs of household battery storage programs in the world. For the households with Nextgen batteries, smart meter data have been collected by the ACT government and will be used to analyse both the economic and technical aspects of the integration of residential battery storage with the local electricity grid. Canberra has a cool climate relative to the rest of Australia. Peak energy consumption generally occurs in winter with morning and evening peaks. In summer, the main energy consumption peak occurs in the late afternoon, around 6 p.m.

The benefits of batteries are well known. For example, they can play an important role in mitigating the mismatch between peak demand and photovoltaic (PV) generation. Excess PV generation during the day can be stored in the battery and used to reduce energy imported from the grid during the evening peak period. This research topic is investigating how the Next Generation Battery Trial has impacted the daily peak demand in Canberra.

Methods:

The project is aiming to analyse all customers who participated in the project since 2016. Currently, the result has analysed 100 connection points (customers) in 2018. The data used here have 5-minute time resolution, and the measures used in this analysis are: PV generation P_{PV}, battery active power $P_{battery}$, and the active power at the meter connection for each household: P_{cp} where cp stands for the connection point. The power import from the grid is positive and exported power is negative. The house active power P_{load} is inferred from given measurements as:

$$P_{load} = P_{cp} - P_{battery} - P_{PV} \quad (1)$$

Assuming the battery would not have changed the customer's behaviour, we estimate the connection point active power without battery P_{cp_NB} as:

$$P_{cp\_NB} = P_{load} + P_{PV} \quad (2)$$

For the two days - the hottest and coldest from BoM records in 2018 (BoM, 2019), we calculated the peak shaving percentage (PSP) for each connection point, as shown in Eq. 3. The peak shaving percentage was based on the difference between the daily peak connection point active power with (P_{cp}^{peak}), without battery ($P_{cp\_NB}^{peak}$). The PSP was then averaged across the 100 connection points.

$$\text{PSP}\ (\%) = \frac{P_{cp\_NB}^{peak} - P_{cp}^{peak}}{P_{cp\_NB}^{peak}} \times 100 \quad (3)$$

Results and Conclusion:

The averaged peak shaving percentage (PSP) over 100 customers was 20.1% on the hottest day (7th Jan 2018) and 10.4% on the coldest day (23rd July). The averaged PSP value has approximately halved on the coldest day compared with the hottest day. The peak connection point active power averaged across customers on the hottest/coldest was 3.39/5.16 kW. It is likely that the lower PSP result in winter was due to the higher peak active power at the connection points.

Demand Manager: Making Electricity Cheaper and More Reliable (Demand response, Energy systems optimisation)

S. He[12*] M. Wallace, A. Liebman and C. Wilson

[1] Monash University, Melbourne, Australia

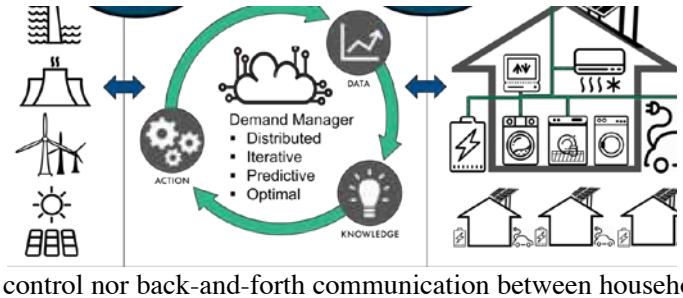
[2] Data61, CSIRO, Melbourne, Australia

Emerging challenges faced by existing power systems, if not met, can lead to an energy future that is less reliable and resilient, and potentially very costly. Demand response (DR) opens new, more efficient and cheaper ways to address those challenges. Moreover, with DR more distributed energy resources and large-scale grid connected renewables (e.g. wind and solar) can be accommodated to further reduce the costs and CO2 emissions.

Real-time pricing (RTP) is a financial incentive mechanism designed to promote DR for consumers. With a pricing signal that varies with the actual demand over time, RTP is proposed to be the most effective mechanism for reducing peak demand and cooperative load shaping in medium and low voltage distribution networks and also impacting the generation and transmission system. Though challenges exist in implementing RTP for residential consumers wherein manually responding to a changing price is difficult and uncoordinated responses can lead to undesired peak demand at what are normally off-peak times.

Previous research has proposed various algorithms to address these challenges, however, they rarely consider algorithms that manage very large numbers of houses and devices while minimizing the costs for consumers and electricity suppliers under RTP prices and maintaining the comfort of consumers in a fast and highly scalable manner. DR is best achieved when a service provider manages the loads over many customers whose total demand can have a material impact on the reliability of the power systems or a specific distribution area. A key challenge for managing large numbers of residential loads is to coordinate millions of solar panels, storage systems, load management devices and other technology in a way that best utilizes the multiple services they can provide to improve the reliability and reduce costs of the grid without scarifying too much consumer comfort.

Demand Manager is a software system developed in this research to address this challenge. This system utilizes large-scale mathematical optimization techniques, which make shifting loads of millions of consumers simple and fast. Specifically, this system optimally schedules devices for households in a distributed but non-cooperative manner, which requires no direct load control nor back-and-forth communication between households but a smart price and a feedback loop between the supplier and households.



The experiment results show that this system minimises the total cost and inconvenience for more than 10,000 households in seconds and has a constant computational complexity, which makes it suitable for real-time applications such as emergency demand reduction and frequency control. Demand Manager will not only empower consumers to better manage their costs of electricity in an easy manner but also improve the reliability and utilization of the existing grid infrastructure through automated DR.

* Contact email: shan.he@monash.edu

THE BLUE ECONOMY CO-OPERATIVE RESEARCH CENTRE: THE OFFSHORE RENEWABLE ENERGY SYSTEMS PROGRAM (Energy Systems Optimisation)

M. Hemer[1*], E. Gray[2] and I. Penesis[3]

[1] Climate Science Centre, CSIRO Oceans and Atmosphere, Hobart TAS, Australia

[2] Queensland Micro- and Nanotechnology Centre, Griffith University, Nathan QLD, Australia

[3] Australian Maritime College, University of Tasmania, Newnham TAS, Australia

Australia has the third largest Exclusive Economic Zone with over 80% being classified as offshore, beyond two nautical miles from the coast and subject to ocean waves, tidal currents and wind. Energy from these and other renewable resources can be captured and converted into electricity for both onshore and offshore use, as well as transformed into energy 'carriers' such as hydrogen, for storage or export. Australian aquaculture is challenged by the lack of suitable inshore sites and the knowledge to operate effectively in remote and/or exposed offshore environments. By overcoming these challenges, Australia can substantially develop its tropical, sub-tropical and temperate aquaculture industries.

The Blue Economy CRC, being launched in mid-late 2019, is a 10-year $329 million research collaboration between 45 national and international partners from industry, research and government, underpinned by a $70 million cash investment from the Federal Government. The CRC will, for the first time, bring the aquaculture and renewable energy sectors together to address the challenges of offshore food and energy production, that leverages the benefits of colocation, vertical integration, infrastructure and shared services. Offshore engineering will be central to this emergence, leveraging decades of experience drawn from the shipping, defence, oil and gas industries.

The objective of the Offshore Renewable Energy Systems program – one of five research programs in the Centre – is to support offshore aquaculture through supplies of lower cost energy and ancillary products (oxygen and freshwater) and to contribute to the cost of offshore infrastructure through the development of exportable energy carriers (e.g. hydrogen). The design and development of renewable energy conversion devices; optimal offshore storage solutions and export products and micro-grid architecture solutions and control systems for intelligent management of integrated offshore end-user demands, will provide a foundation to enable other emissions-intensive offshore industries to transition to a future low-emissions Australia.

* Contact email: mark.hemer@csiro.au

† Group URL: http://www.blueeconomycrc.org.au

Advances in Aluminium-ion Batteries
Battery Storage

Nicolò Canever[1†], Shalini Divya[1†], Nicolas Bertrand[1†], Jacob Johnston[2*†], Thomas Nann [2†]

[1] School of Chemical and Physical Sciences, University of Victoria, Wellington, New Zealand.

[2] School of Mathematical and Physical Sciences, University of Newcastle, NSW, Australia.

Aluminium batteries have the potential to provide high capacity while offering greatly reduced cost in comparison to their lithium counterpart. However, an expensive ionic liquid electrolyte and poorly performing cathodes are holding back their potential. Further research into alternative electrolyte and cathode materials is needed. Herein we present an electrolyte which is roughly an order of magnitude cheaper in price while achieving comparable performance to the standard 1-ethyl-3-methylimidazolium chloride ionic liquid electrolyte. We also showcase how the transition metal chalcogenide $MoSe_2$ can effectively intercalate $[AlCl_4]^-$ while MoS_2, although crystallographically similar, does not show appreciable signs of intercalation.

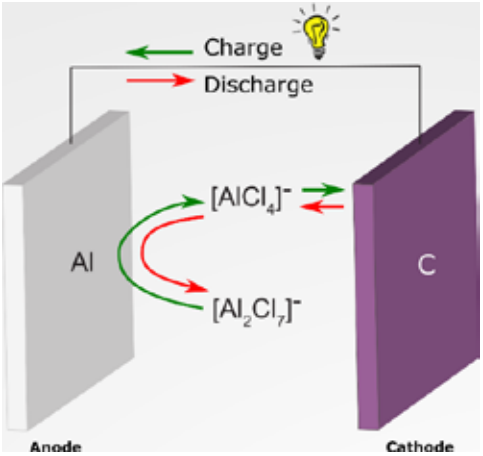


Figure 1: The general aluminium battery mechanism.

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* Contact email: Jacob.M.Johnston@uon.edu.au

† Group URL: https://www.nannomaterials.com/

Energy security: Objective/Subjective complexity and transnational norm diffusion (Climate and energy policy)

Kamonphorn Kanchana[1,2*] and Hironobu Unesaki[1]

[1] Graduate School of Energy Science, Kyoto University, Kyoto, Japan

[2] Faculty of Political Science and Public Administration, Chiang Mai University, Chiangmai, Thailand

While the term 'energy security' is widely used among decision makers and scholars, its conceptualization is controversial. Seeking to understand why it is nearly impossible to reach a consensus over what exactly energy security is, this paper revisits the conceptualization of energy security by answering four basic yet fundamental questions based on security studies. We consider the objective/subjective complexity as a crucial factor in shaping the perception and approach towards energy security that consequently affect the following interpretation of relevant referent objects, security issues, and remedial actions. The controversy between objective view and analysis of energy security and the intersubjective relationship between energy and other objects, which results in the different interpretation of energy risks, have also been discussed. This study then dichotomizes energy security risks into physical and structural risks, which helps create a clearer picture of energy security as a concept. As per the discussion over energy security and its transnational norm diffusion reflected from national energy security policies, this paper argues that, due mainly to the objective/subjective complexity, energy security is highly context-dependent to the point that transnational norm diffusion could be not be easily established, especially with regards development gap and geopolitics of energy resources.

* Contact email: kamonphorn.k@cmu.ac.th

Rethinking Biofuels in Australia

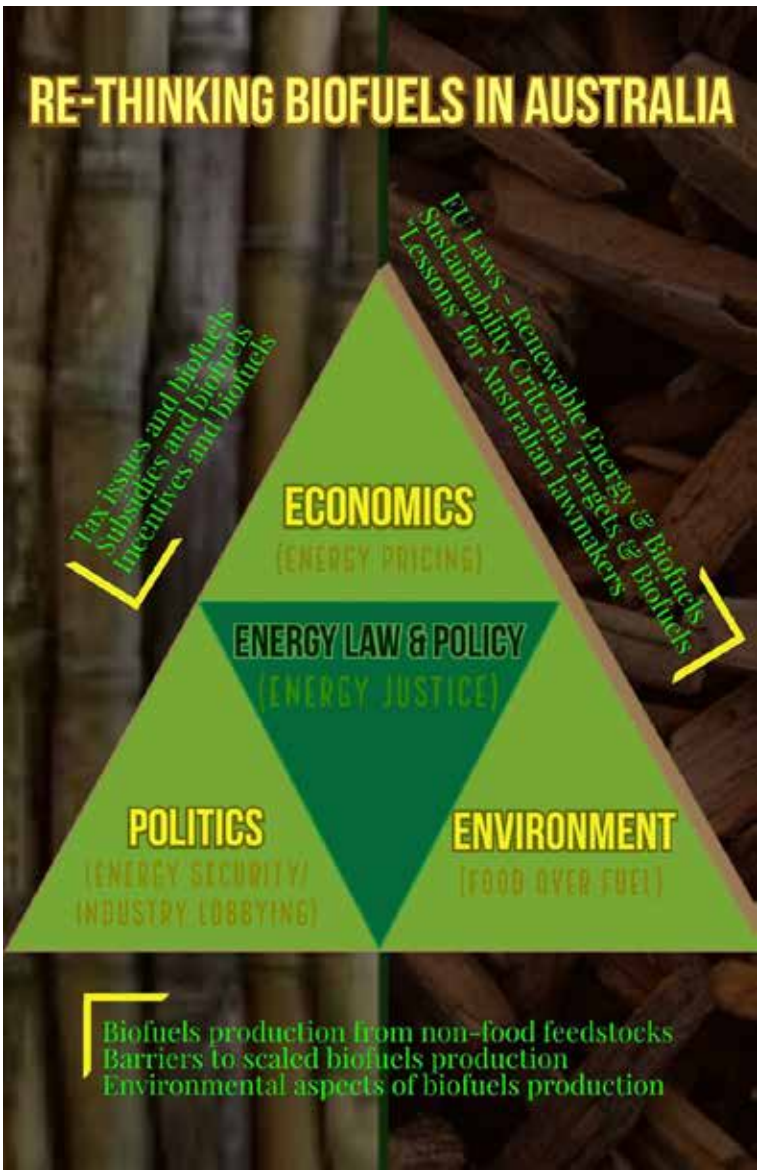
(Conference Theme: Renewable Fuels)

Diane Kraal [a, *], *Victoria Haritos* [b], *Rowena Cantley-Smith* [c]

[a] * *Monash Business School, Monash University, Melbourne, Australia*

[b] *Faculty of Engineering, Monash University, Melbourne, Australia*

[c] *Law Faculty, Monash University, Melbourne, Australia*



The research re-thinks the outcomes of major technical studies on biofuels published in Australia between 2007 and 2014 to inform current energy policy. We examine selected biofuel developments in the EU and also present the latest developments in biofuels production, such as ethanol and renewable diesel obtained from non-food feedstocks.

This research empirically and theoretically examines a number of questions. What is still valuable from early 2000s Australian biofuels studies? What type of fiscal and regulatory support could encourage biofuels innovation and investment in Australia? Can EU legal frameworks on biofuels be transitioned to policy in Australia? Are there further technology breakthroughs in biofuels needed? These questions have been developed by reference to advanced biofuels, policies and law outside of Australia, and the contention that economic benefit is no longer considered the sole criteria for evaluating renewable energy projects. Our results are analysed through the lens of 'energy justice' where it is argued that not only economics (energy pricing), but also environmental (sustainable fuel production) and political (energy security) considerations are needed to progress Australia's biofuel policies and laws.

Investment is needed to promote the important role of biofuels in the transition of the Australian energy market towards a sustainable future. Appropriate policy, laws, and regulations are essential drivers of such investment and the ultimate success of the Australian biofuels sector.

Free-Standing 3D Hierarchical Porous Nanostructured Electrodes for High-Energy Density and Long Cycle Life Lithium–Sulfur Batteries
(Battery Storage)

B. Liu[1] and A. Tricoli[1*]

[1] Nanotechnology Research Laboratory (NRL), Research School of Electrical, Energy and Materials Engineering (RSEEME), Australian National University, Canberra, ACT, 2601, Australia

The lithium–sulfur (Li–S) system is a promising material for the next-generation of high energy density batteries with application extending from electrical vehicles to portable devices and aeronautics.[1] Despite progress, the energy density of current Li–S technologies is still below that of conventional intercalation-type cathode materials, due to limited stability and utilization efficiency at high sulfur loading. Here, we present a conducting polymer hydrogel integrated highly performing free-standing 3D monolithic electrode architecture for Li–S batteries with superior electrochemical stability and energy density. The electrode layout consists of a highly conductive three-dimensional network of N,P co-doped carbon with well-dispersed metal-organic framework nano-domains of ZIF-67 and HKUST-1. The hierarchical monolithic 3D carbon networks provide an excellent environment for charge and electrolyte transport as well as mechanical and chemical stability. The electrically-integrated MOF nano-domains significantly enhance the sulfur loading and retention capabilities by inhibiting the release of lithium polysulfide specifies as well as improving the charge transfer efficiency at the electrolyte interface. Our optimal 3D carbon-HKUST-1 electrode architecture achieves a very high areal capacity of > 16 mAh cm^{-2} (C_V ~ 1230.8 mAh cm^{-3}) with capacity retention of 82 % at 0.2C for over 300 cycles, providing an attractive candidate material for future high energy density Li–S batteries.

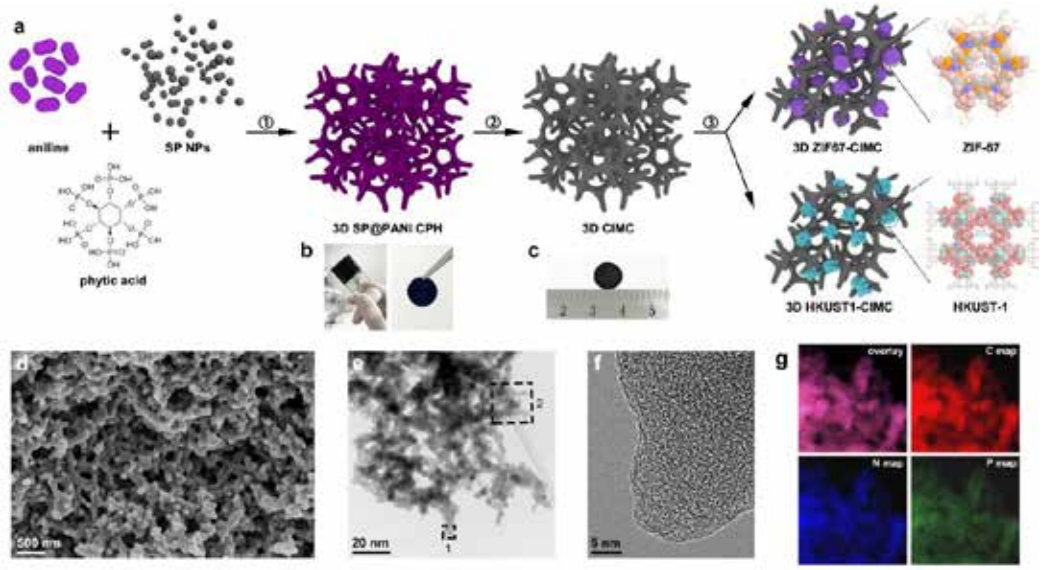


Figure 1: Synthesis and characterizations of the monolithic 3D carbon (CIMC)-MOF electrodes.

References

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* Contact email: antonio.tricoli@anu.edu.au
† Group URL: http://nano.cecs.anu.edu.au/index.html

A snapshot of rapidly falling battery costs
(EVs and FCEVs)

Thomas Longden [1*]

[1] ZCEAP Grand Challenge Senior Research Fellow, ANU, Canberra, Australia

In the last few years there have been numerous studies that have focused on the costs of battery packs used in battery electric vehicles (BEVs) to assess whether technological advances and the impact of increased production have outpaced expectations (Edelenbosch et al. 2018; Nykvist and Nilsson 2015; Sakti et al. 2017). While uncertainty about the actual cost of batteries is a closely guarded secret of those in the industry and are hard to assess using the sale price as they may be sold at a loss in order to comply with regulations (such as California's ZEV mandate) or to win a greater market share (Nykvist et al. 2019); there are a range of estimates published in numerous studies, including IEA (2018) and Longden (2014).

The publication of the International Energy Agency Global Electric Vehicle Outlook 2018 presents an opportunity to assess how far battery costs have fallen in the last few years. This study compares estimates from a range of sources to assess the current cost of batteries. These sources are a selection of studies that include a cost estimate per kWh and the size of the battery in terms of kWh.

Figure 1 contains this comparison of costs with the cost per kWh ($/kWh) on the y-axis and the cost of the battery pack ($ thousand) on the x-axis. The grey arrows in Figure 1 show how the estimates have decreased for a 21kWh and 85kWh battery pack between 2011 and 2018. There is notable consistency in the battery estimates across sources once the battery capacity (shown as kWh) is considered.

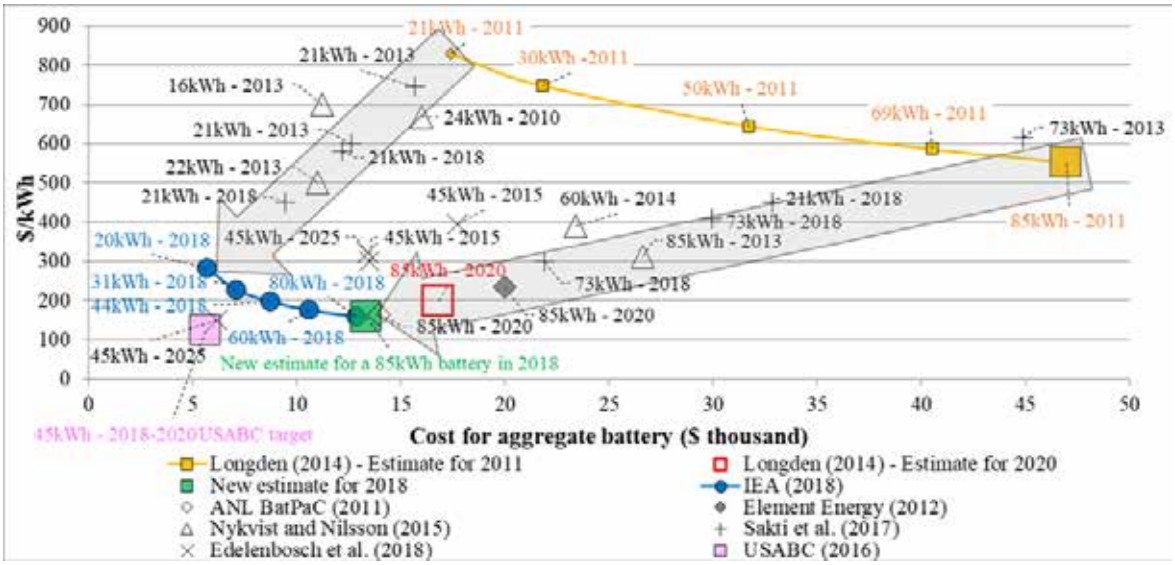


Figure 1: Estimates of battery costs between 2010 and 2025 in terms of battery capacity, $/kWh and aggregate cost

Summary - This battery cost estimate for 2018 was developed for use in WITCH (World Induced Technical Change Hybrid) as it is an integrated assessment model designed to assess climate change mitigation and adaptation policies (Emmerling et al. 2016). However, it will be useful for a range of projection studies and of interest to academics and decision-makers in Federal and State government departments, as well as key stakeholders in industry and NGOs.

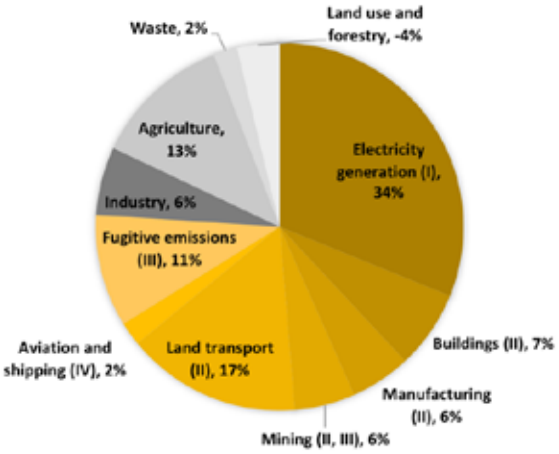
* Contact email: tom620@gmail.com

DEEP DECARBONISATION OF ENERGY SECTOR IN AUSTRALIA
(Energy Systems Grid Integration)

B. Lu *†, A. Blakers, M. Stocks, C. Cheng and A. Nadolny
The Australian National University, Canberra, Australia

Australia is leading the world in the deployment of renewable energy. In 2019, about 6 gigawatts of solar photovoltaics and wind turbines are expected to be installed, which is equivalent to 250 watts per capita compared with about 50 watts per capita for the European Union, the United States, China and Japan. Energy-related greenhouse gas emissions account for more than 80% of the total emissions in Australia (Figure 1-a). Deep decarbonisation of energy sector can be achieved through large-scale deployment of renewable energy in electricity sector, along with direct or indirect electrifications of heating, transportation and machinery (Figure 1-b).

In this study, a series of 100% renewable energy scenarios for the Australian National Electricity Market are simulated using high-resolution meteorological and energy demand data. The modelling results show that energy supply and demand balance can be effectively maintained through a synergy of energy storage, large-scale grid interconnection and demand response enabled by distributed energy resources and the Smart Grid. Significantly, with a right mix of energy generation, storage and transmission technology, the levelised cost of 100% renewable energy can be competitive with current electricity price in the wholesale market and is lower than the cost of new-build coal and gas power stations in Australia.



(a)

Category	Pathways towards deep decarbonisation of energy sector	
I	Renewable energy	• Power generation: solar photovoltaics, wind, existing hydro and bio • Energy storage: pumped hydro, batteries and thermal energy storage • Electricity transmission: high-voltage direct- & alternating-current
II	Direct electrification	• Heating: heat pumps, electromagnetic and electric furnace • Transportation: electric vehicles • Machinery: electric mining and construction equipment
III	Vanishing as fossil fuels phased out	
IV	Renewable electro-fuels (indirect electrification): hydrogen and synthetic fuels	

(b)

Figure 1: (a) Australia's greenhouse gas emissions by sector in 2018 [1]; (b) Pathways towards deep decarbonisation of energy sector in Australia.

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* Contact email: bin.lu@anu.edu.au
† Group URL: http://re100.eng.anu.edu.au

INCREASING THE PV HOSTING CAPACITY WITH CENTRALISED INVERTER CONTROL (Energy Systems Optimisation)

P.Lusis[1*], L. L. H. Andrew[1*], A.Liebman[1*] and G.Tack[1*]

[1]Faculty of Information Technology, Monash University, Melbourne, Australia

Last year, the total number of rooftop installations in Australia surpassed 2 million [1], reaching 50% penetration of residential rooftop solar in some areas [2]. A prominent issue is voltage rise outside the operational limits, which predominantly occurs in low voltage residential networks. As a result, the number of residential areas waiting for network upgrade is unprecedented. Various research and demonstration projects are looking at non-wire alternatives to regulate voltage without costly network augmentation. The next generation solar PV inverters with reactive power support (Volt/VAr control) have already become the industry standard. However, local voltage regulation is network-agnostic, meaning the inverter is not aware of its location in the network or the effect it has on other power electronics, leading to suboptimal system operation. When looking in the future with residential areas beyond 50% PV penetration combined with a growing number of smart IoT devices and EVs, the orchestration of the hardware will be required.

We studied to what extent it is possible to increase PV hosting capacity and maintain voltage in residential distribution networks by enabling the communication between PV inverters and a supervisory controller at a central location. Instead of providing reactive power support following the Volt/VAr droop curve, each inverter sends the voltage measurement to a central controller, where the information from all nodes is processed via a convex optimisation algorithm and returned as optimum active and reactive power setpoints for each inverter. Whether the central controller is operated by a distribution network system operator (DNSP), an aggregator or another party, this enables visibility and minimum energy curtailment and line losses. By applying centralised inverter control on an 18 bus low voltage network, the hosting capacity increased by more than 10% in comparison with Volt/VAr control.

Continuing adding more solar PV systems would result in energy curtailment even with the coordinated control approach. We found that PV systems at the end of the line, where most of the overvoltage events occur, experience the highest output reduction. To avoid excess energy curtailment for those customers, we introduce a fairness objective in our optimisation algorithm that fairly distributes the energy reduction among the controllable inverters. Even with the fairness objective, the total energy curtailment and line losses can be halved in comparison with Volt/VAr control.

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Security assessment of the electric power system using a new intelligent short-term planning method

(energy system optimisation)

S. Meghdadi* , G. Tack, A. Liebman
Faculty of IT, Monash University, Melbourne, Australia

The transition to a new low emission energy future, with a changing mix of generation and load types with significant growth in renewable energy generation and the exit of ageing fossil fuel power plants increases technical challenges for electrical grid planning and operation, where stability and security of power systems without interruption of customer service is of prominent importance. Due to the fast-paced change of power system dynamics, such as reduction of available inertia and its effect on transient stability, also known as large signal rotor angle, analysis is vital. Machine learning (ML) methods provide capable options to be added to power system short term planning (ACOPF) ensuring security of operation replacing time domain simulations and mathematical approximation methods. However; traditional machine-learning algorithms will have difficulties fitting a proper function to not only accurately detect all unstable instances, but also predict the time of instability of the power system. Introduction of time of instability will not only efficiently counteract the reduction of inertia, but will also provide cheaper generation scenarios. This study introduces a new systematic and computationally efficient decomposition approach to account for system security within short term planning using well-known machine leaning tools. The immediate value of this paper is that it provides extendable, computationally efficient, and clear logical guidelines for using supervised machine-learning tools to assess transient stability status and time of instability simultaneously. The effect of electronically coupled generators is out of the scope of this work. Therefore, the IEEE nine bus test case is chosen for studying system security for especially designed postulated load scenarios, reporting very high computational efficiency and high accuracy and quality solutions. It distinguished stable and unstable cases in a validation data set very accurately, with only 0.57% error. It also showed a high precision in predicting the time of instability, where the predicted time of instability had 6.8% error with mean absolute error as small as 0.0145.

* Contact email: Seyedali.meghdadi@monash.edu

WATER FOOTPRINT OF THERMOELECTRIC POWER PRODUCTION IN AUSTRALIA (Climate and Energy Policy)

S. Nair* and W. Timms
School of Engineering, Deakin University, Australia

Water and energy are closely linked. Water is required for the production of energy. Water availability often impacts the choice of the power production technology and installation sites [1]. As the scarcity of water is exacerbated by population growth and climate change, there is a great competition for water between electricity production and other consumers.

Water use associated with electricity production has not received enough attention in Australia though it is a dry continent and water use efficiency will be increasingly important policy issue with changing climate [2]. Therefore, this study was aimed at bridging the knowledge gap in this aspect by investigating the water withdrawal and consumption of major thermoelectric power plants in Australia. The water use intensities (GL/GWh) associated with each fuel-technology-cooling type combination was applied to corresponding plants and the total annual withdrawal and consumption quantities were estimated for the National Electricity Market (NEM) region.

The annual water withdrawal and consumption of around fifty thermal power plants over the size of 50 MW were analysed by state and fuel type and are shown in Figure 1 a and b respectively.

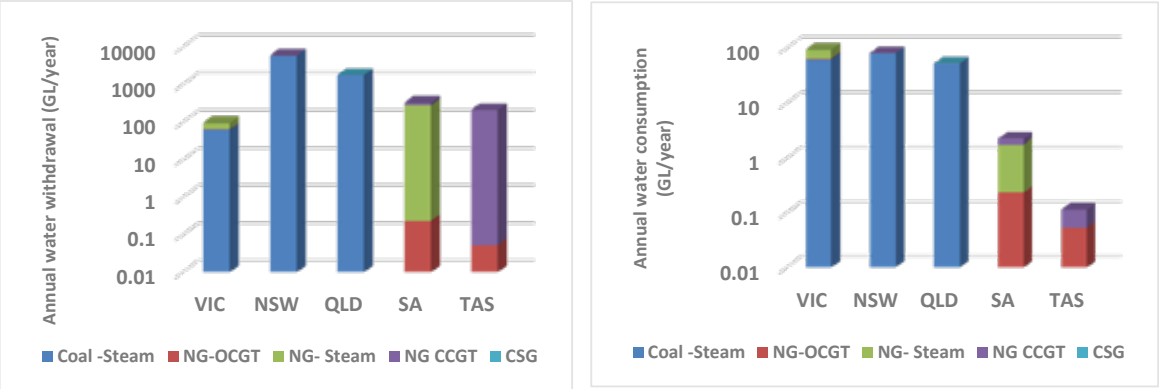

Figure 1 a): Annual water withdrawal, and **b)** water consumption of thermal power plants in Australia by state and fuel type. (NG –Natural Gas, OCGT – Once Through Gas Turbine, CCGT – Combined Cycle Gas Turbine, CSG – Coal Seam Gas)

It can be seen that coal power plants dominate both water withdrawal and consumption in Australia. NSW dominates the water withdrawal (5838 gigalitres (GL)) chart due the presence of large plants with once through cooling system, while all the major coal powered plants in Victoria use recirculating cooling, which is reflecting on their relatively lower withdrawal and higher consumption rates. A holistic assessment is required to shed more light on the water use and associated environmental impacts of energy sector including primary energy extraction and conversion stages. Regular reporting of accurate data by concerned stakeholders is imperative to achieve this aim.

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* Contact email: sudeep.nair@deakin.edu.au

The adoption of ESCO industry in Shanghai – Contextualization as an innovation in cities (Climate and energy policy)

Yuan Peng[1*] and Xuemei Bai[1]
1 The Fenner School of Environment & Society, Australian National University, Canberra, Australia

Cities in rapidly developing regions like Shanghai have been confronted with multiple challenges such as rapid development, industrial restructuring, energy security, climate mitigation, and air pollution(Peng and Bai, 2018). Improving energy efficiency could be a multi-effect solution for tackling these problems. Energy Performance Contracting (EPC), provided by Energy Service Companies (the ESCO industry), is a market-based mechanism with double benefits for those cities, in terms of both promoting energy efficiency gains and enabling local service industry development. The existing literature examines the expansion and diffusion of EPC, mainly from the business and technical perspectives; however, embedding an emerging industry such as the ESCO industry is a complex social-economic-institutional process, and the way this is handled might determine the success or failure of its adoption. To understand this contextualization process, this research aims to answer the following two questions "What are the key processes/elements in the contextualization of EPC in adopter cities?" "How innovation can be successfully translated into new contexts?"

We take Shanghai as a case study city and examine the EPC adoption process from the articulation of the vision to adopt EPC, learning modes, and actors' interactions. In addition, we identify and compare some innovative elements that emerged during the contextualization with those in the original contexts from which Shanghai learned. As shown in Figure 1, we argue that contextualization requires mobilization and realignments of actors, resources, and institutional arrangements within the process of learning, which involves much more than simple duplication and often results in distinctive outcomes, i.e. a new social, economic and institutional configuration. Thus, in many ways is an innovation in itself (Peng et al., 2019). This new configuration, which is central to EPC practice in contextualization, is supported by various "horizontal linkages" with the original cases, which include information/knowledge transfer and learning via actor interactions across cases, but the focus of learning shifts from external (i.e. from the original context) to internal (i.e. within the new context) during the contextualization process. These findings contribute to an in-depth understanding of how innovations like EPC can transfer across cases, which is a significant gap in the current system innovation literature, and may inform practice in terms of how to facilitate the scaling of proven mechanisms to achieve sustainability transitions.

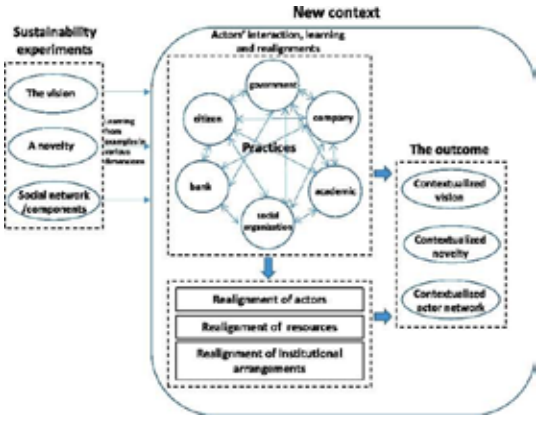

Figure 1: Horizontal linkages and the innovative processes in contextualization.

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* Contact email: yuan.peng@anu.edu.au
† Group URL:

A Highly Flexible Data-Rich Optimisation Model of the National Energy Market

Steven Percy
The Victoria Energy Policy Centre, Victoria University, Melbourne, Australia

In 2018 the Australian Energy Market Operator (AEMO) released the Integrated System Plan (ISP), a scenario based engineering and economic model for the National Electricity Market (NEM). As part of the ISP, AEMO made public all main input assumptions and datasets [1]. The modelling in the ISP used PLEXOS® Simulation Software to develop a long-term optimisation model that modelled a simplified version of the NEM to optimise infrastructure investments and a short-term dispatch model that optimised hourly dispatch with a day ahead window. In this research, we have built on the rich ISP data resource and the modelling framework in [2] to develop a highly flexible linear optimisation model of the NEM, including optimal storage, transmission, generation investment and optimal generator dispatch to most economically achieve government policy such as the renewable energy target, Figure 1 shows the geographical configuration of this model. This modelling improves over the state of the art optimisation solvers on cloud computing to simulate a one-year 30-minute interval optimisation window that allows sizing of renewable resources while considering the yearly seasonality and the short-term coincidence between demand and geospatial renewable resources. Testing the economic impact of new renewable energy policy can occur within the modelling framework, providing better advice before implementation. Strategic generator bidding has been estimated from historical bidding patterns that improve results of simply using generator short-run marginal cost as in [2].

The results from the model show the lowest cost storage and generation infrastructure necessary to meet government policy targets. The half-hourly model results provide a forecast of regional spot price, resource utilisation, transmission flow, transmission constraints, total renewable curtailment, and revenue from new and existing market players. The poster presents a model description and results summarising the transmission zone storage and renewable generation required to achieve emissions targets and associated costs.

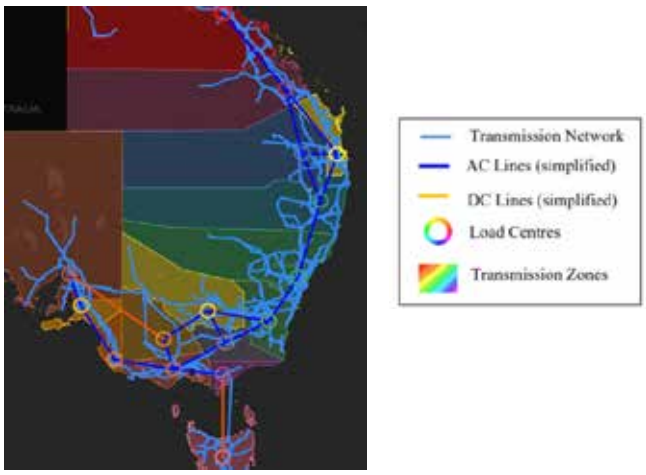

Figure 1: Model configuration showing the NEM transmission zones, load centres and transmission lines.

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* Contact email: Steven.Percy@VU.edu.au
† Group URL: www.VEPC.org.au

Long duration storage supports a reliable, flexible and affordable future NEM

Pumped hydro, hydrogen and other storage technologies

Dr Cameron Potter[1]
[1] Future Energy Market Strategist, Hydro Tasmania

Australia is on the cusp of a national transformation of our National Electricity Market. A significant proportion of our current fossil fuel fired generation fleet will retire and be replaced by sources with different operating characteristics, like wind and solar.

In its 2018 Integrated System Plan, the Australian Energy Market Operator forecast that 17,000MW of utility storage will need to be developed as part of a least cost transition of the electricity sector by 2040. Much of this could be needed sooner if the retirement of coal-fired generation occurs quicker than projected.

So what does that mean for pumped hydro? As supply becomes more variable, balancing supply and demand will become a greater challenge for the nation. This is where energy storage comes in. Pumped hydro can provide the flexible, responsive and dispatchable capacity and storage needed to meet Australia's growing energy needs.

Pumped hydro can offer long duration storage to help meet some of the emerging challenges like solar cycle balancing and wind droughts. And when energy supply exceeds demand, that surplus energy can be used to pump water back into storage. Consuming the excess energy supports the development of more wind and solar – thus providing access to more low-cost energy.

As part of Tasmania's *Battery of the Nation* initiative and supported by the Australian Renewable Energy Agency (ARENA), Hydro Tasmania's analysis shows Tasmania has a competitive and cost effective solution that forms part of Australia's least-cost future energy system. Further interconnection between Tasmania and Victoria will unlock Tasmania's renewable energy potential in both our existing hydropower system and future development potential for pumped hydro. It will also unlock opportunity for additional wind and solar both in Tasmania and across the NEM.

This is your chance to hear more about this exciting initiative.

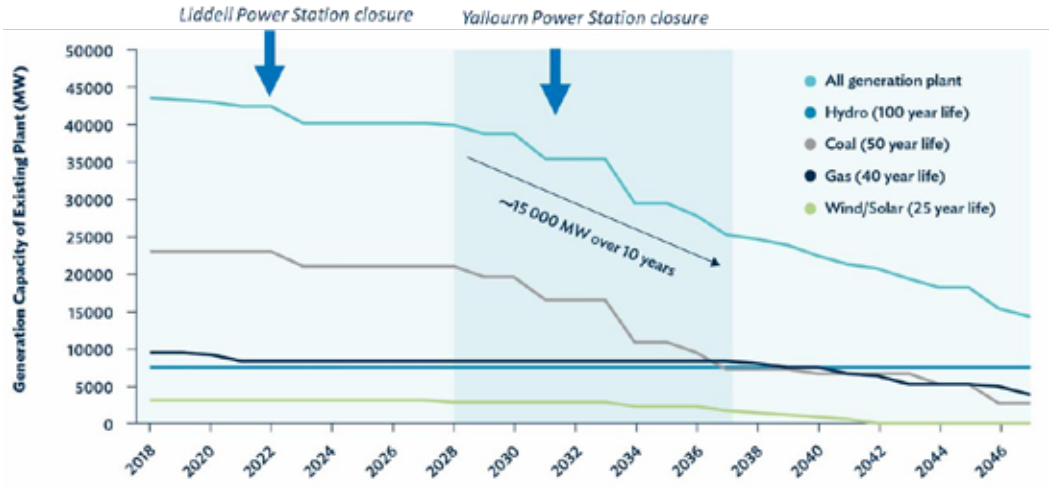

Figure 1: Expected retirement profile of existing generation assets in the NEM (based on life expectancy) (see [1]).

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Contact email: batteryofthenation@hydro.com.au
Group URL: www.hydro.com.au/clean-energy/battery-of-the-nation

Ancillary Services 4.0: One Step Closer to 100% Renewable-Powered Grid (Demand Response)

S. Ali Pourmousavi[1*], Juan M. Morales[2ǂ], and Henrik Madsen[3†]

[1] Department of Electrical and Electronics Engineering, the University of Adelaide, Adelaide, Australia

[2] Department of Applied Mathematics, University of Málaga, Málaga, Spain

[3] Department of Applied Mathematics and Computer Sciences, Technical University of Denmark, Kgs. Lyngby, Denmark

The fourth industrial revolution, called Industry 4.0, has already started to affect many businesses [1]. Industry 4.0, in a nutshell, employs transformative technologies to connect the physical and digital worlds together through advanced automation and robotics, machine-to-machine and human-to-machine communication, artificial intelligence and machine learning, sensor technology and data analytics [2]. The basic principle of Industry 4.0 is that by connecting equipment, workpieces and systems, businesses can build intelligent networks along the entire value chain capable of controlling each other autonomously [2].

In the power system industry, the transition to Industry 4.0 is happening, albeit slowly. ICT solutions and artificial intelligence along with advanced metering are becoming widespread as the backbone of the Industry 4.0. In this paradigm, consumers are expected to play an active role in power system operation, as a part of the entire value chain, through Direct and Indirect demand response programs (DRPs). Despite the tremendous efforts, the true potential of consumers' flexibility has yet to be exploited. This is mainly due to issues related to privacy, welfare, and scalability of Direct DRPs as well as complexity, computation and communication intensity, high cost of implementation, and cyber-security challenges of Indirect DRPs. In addition, the privilege of participating in DRPs is only given to large industrial loads in many cases and the benefit of using demand flexibility is only limited to the high-voltage network operators.

By leveraging the Industry 4.0 concept and technologies (e.g., Internet-of-Things (IoT) and advanced machine learning methods) and smart grid tools (e.g., Advanced Metering Infrastructure (AMI) and home energy management systems (HEMS)), we hypothesised a disruptive ancillary services (AS) mechanism, called AS 4.0, that helps getting closer to a 100% renewable grid by facilitating demand flexibility participation in real-time grid operation. It works based on real-time prices generated by the operators at different voltage levels and communicated to consumers' HEMS through one-way links. The proposed framework enables multi-carrier energy interoperation for the benefit of the power system's operation. In this mechanism, AS procurement is extended to the distribution system operators too, which enables the integration of more rooftop PV in the distribution networks. In this poster, the AS 4.0 framework will be introduced in detail, and its advantages and challenges will be outlined. Moreover, a roadmap will be given to illustrate the implementation of AS4.0 in practice.

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* Contact email: ali.pourmousavi@gmail.com
ǂ Group URL: https://sites.google.com/view/groupoasys/home
† Group URL: http://henrikmadsen.org/

LAW AND POLICY FOR RENEWABLE GAS IN AUSTRALIA
Conference Theme: Gas Markets

J. Prest.[1*]

[1] ANU College of Law and ANU Energy Change Institute,
Australian National University, Canberra, Australia

The renewable gas sector – involving biomethane and 'green' hydrogen - is well developed overseas. Renewable gases such as biomethane and 'green' hydrogen are presently the least developed form of renewable energy in Australia. How to increase investment in this sector is a key question for law and policy makers, especially as there are capacity and economic limits to the electrification of all energy use.

In terms of injecting biomethane in pipelines: no injection projects yet exist in Australia. By contrast, at least 40 biomethane injection projects exist in the USA, more than 200 in Germany and 25 in Denmark. At the same time, Australia's emerging renewable gas sector presents many economic opportunities, many of which are currently underexploited. Biomethane offers important pathways to decarbonise the gas sector. In overseas jurisdictions, including in the USA, projects involving pipeline injection involve various combinations of clean-up technologies to comply with existing standards.

Pipeline injection of biomethane that does not conform to the Australian Standard AS4564-2011 is legally problematic. Distribution companies are legally required under State level Gas Safety Acts to inject only gas that is within the specification and cannot lawfully convey off-spec gas.

In biomethane projects overseas, system injection points are typically controlled by gas distribution companies who can terminate injection if gas is 'off-spec'. Biomethane proponents will need to develop projects in partnership with distribution companies. It is recommended that the biogas industry invest in biomethane upgrading facilities, using a hub model and co-location of biogas producers (for shared costs and economies of scale).

The current Australian regulatory framework governing biogas injection contains some uncertainty: the legislative framework is specific to natural gas rather than to biogas or biomethane. This legal uncertainty is a barrier to investment in both biomethane and hydrogen.

The regulatory approach to the injection of non-standard (off-spec) gas has broader implications, it is relevant to the development of the renewably produced hydrogen gas industry in Australia. Many of the policy and technical issues relating to the pipeline injection of biomethane are similar to those relating to the pipeline injection of hydrogen, questions of departure from AS4564-2011 will be navigated by the hydrogen industry in conjunction with Standards Australia. It is likely that green gas reform of the Australian gas industry will be led by the hydrogen sector.

Direct incentives to reward pipeline injection of biomethane are not available in Australia at either federal or state level. A future specific incentive tailored to biomethane injection could draw upon existing models of policy/ law applied overseas: (i) feed-in tariffs for renewable gas (ii) certificates/ guarantees of origin of renewable gas (iii) guaranteed priority of access to gas networks for renewable gas that meets quality standards.

A national certificate-based incentive mechanism is recommended. This could involve recognition and a guarantee of origin scheme (i.e. voluntary green gas, similar to green power); later, an incentive could be introduced via a market obligation mechanism similar to the renewable energy target (RET), involving tradeable green gas certificates. This approach includes policy concepts and design elements already familiar to the Australian energy industry and government.

* Contact email: james.prest@anu.edu.au

In situ recombination junction between p-Si and TiO_2 enables high efficiency perovskite/Si tandem cells

(Solar renewable electricity generation)

Heping Shen,[1,*] Stefan T. Omelchenko,[2] Daniel A. Jacobs,[1] Sisir Yalamanchili,[2] Yimao Wan,[1] Di Yan,[1] Pheng Phang,[1] The Duong,[1] Yiliang Wu,[1] Yanting Yin,[3] Christian Samundsett,[1] Jun Peng,[1] Nandi Wu,[1] Thomas P. White,[1] Gunther G. Andersson,[3] Nathan S. Lewis,[4] Kylie R. Catchpole[1]

[1]Centre for Sustainable Energy Systems, Research School of Engineering, The Australian National University, Canberra 2601, Australia.
[2]The Joint Center for Artificial Photosynthesis, California Institute of Technology, Pasadena, CA 91125, USA
[3]School of Chemical and Physical Sciences, Flinders University, Adelaide, SA 5042, Australia.
[4]Division of Chemistry and Chemical Engineering, California Institute of Technology, Pasadena, CA 91125, USA.

Increasing the power conversion efficiency of silicon (Si) photovoltaics is a key enabler for continued reductions in the cost of solar electricity.[1, 2] Herein we describe a two-terminal perovskite/Si tandem design that increases the Si cell's output in the simplest possible manner: by placing a perovskite cell directly on top of the Si bottom cell. The advantageous omission of a conventional interlayer eliminates both optical losses and processing steps, and is enabled by the surprisingly low contact resistivity attainable between n-type TiO_2 and Si, established here using atomic layer deposition. We fabricated proof-of-concept perovskite/Si tandems on both homojunction and passivating-contact heterojunction Si cells to demonstrate the broad applicability of the interlayer-free concept. Stabilized efficiencies of 22.9% and 24.1% were obtained for the homojunction and passivating contact heterojunction tandems respectively, which could be readily improved by reducing optical losses elsewhere in the device. This work highlights the potential of emerging perovskite photovoltaics to enable low-cost, high-efficiency tandem devices through straightforward integration with commercially relevant Si solar cells.

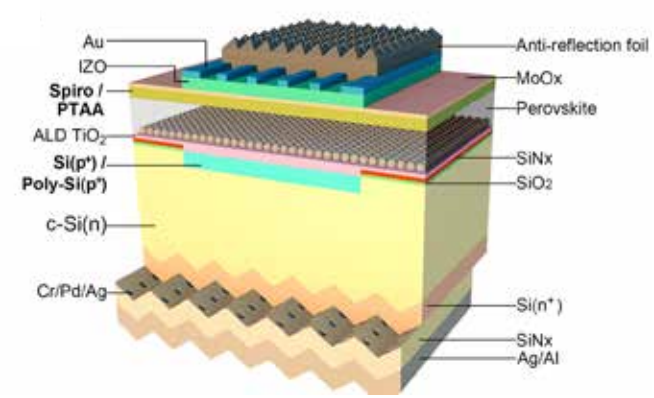

Figure 1: Schematic of the interconnect-free monolithic perovskite/c-Si tandem solar cell

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* Contact email: heping.shen@anu.edu.au
† Group URL: https://www.perovskitegroup.com.au/

CATALYTIC ACTIVITY OF ZnO POLAR SURFACES FOR HYDROGEN PRODUCTION

(Pumped Hydro and Hydrogen Technologies)

C. Tang[1]

Energy Change Institute, The Australian National University, Canberra, Australia

As a material with a wide range of applications in hydrogen production from water splitting, optoelectronic devices and gas sensing, zinc oxide (ZnO) has attracted extensive research interest. Specifically, the activity of ZnO as catalysis is sensitive to its surface energies. However, accurate calculation of surface energies for polar (0001) surfaces of wurtzite ZnO is difficult because it is impossible to decouple the two inequivalent (0001)-Zn and (000-1)-O surfaces.

By using a heterojunction model we have transformed the uncertainty of the surface energies into that of interface energies which is much smaller than the former (because of the passivation of dangling bonds) and hence provided an approach for estimating the surface energies to a high degree of accuracy. It is found that the oxygen terminated surfaces are more stable than their Zn-terminated counterparts within the major temperature and oxygen partial pressure range accessible to experiment. The instability of Zn-terminated polar surfaces explains the experimentally observed high activity of these surfaces.

These results provide insights into the modification of the surface stability and activity of ZnO nanoparticles for catalytic applications such as hydrogen production from water splitting. Moreover, this method provides a general approach for estimating the activity of polar surfaces of other metal oxide catalysts.

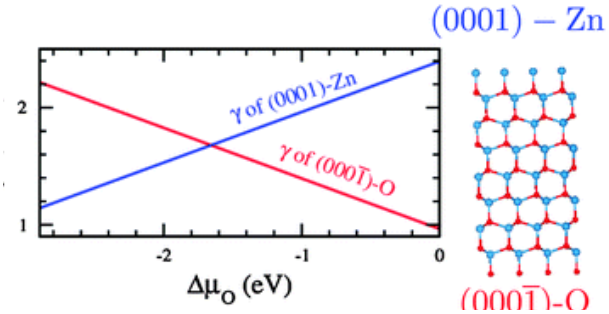

Figure 1: Compared to O-terminated surfaces, Zn-terminated surfaces have higher surface energies and are more active as effective catalytic sites in the accessible experimental oxygen chemical potential (see [1]).

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[1] Contact email: chunguang.tang@anu.edu.au

THE SCOPE OF ZERO-CARBON STEELMAKING

(Renewable Fuels)

Mahesh Venkataraman[1],*, Zsuzsanna Csereklyei[2], Alireza Rahbari[1], Emma Aisbett[3] and John Pye[1]

[1] Research School of Electrical, Energy and Materials Engineering, The Australian National University, Canberra, Australia

[2] School of Economics, Finance and Marketing, RMIT University, Melbourne, Australia

[3] School of Regulation and Global Governance, The Australian National University, Canberra, Australia

The environmental cost associated with traditional steelmaking routes is quite high, accounting for ~6.4% of the total global anthropogenic emissions. In 2016–2017, IEA [1] presented a long-term CO_2-emissions pathway for different sectors, with their <2°C (IEA-2DS) and 1.75°C (IEA-B2DS) scenarios. For some processes, such as steel making, restricting GHG-emissions within these targets is quite challenging, with no evident pathway based on conventional routes. It is important to understand what (mix of) technologies have the potential to align with the CO_2-emissions target set by IEA. Our analysis aims to answer the question — whether or not, new breakthrough technological intervention is required in the context of steelmaking? For this purpose, we analyse the C-emissions from steel industry on a global scale.

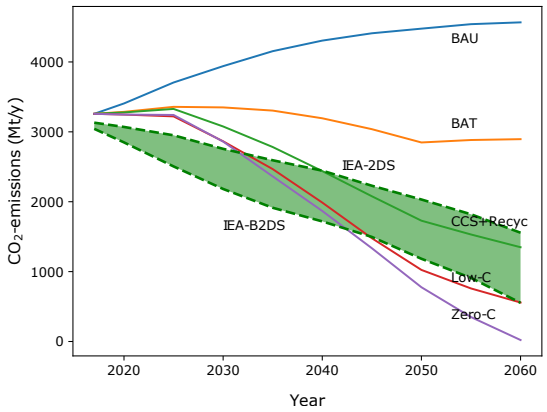

Figure 1: 2017–2060 emissions under different scenarios.

The evaluated technologies include fossil-based (blast furnace, natural gas and coal based DRI), pilot-scale (HiSarna, electrowinning and H_2–DRI) and research stage (pyroelectrolysis) routes. The model evaluates 5 scenarios with different penetrations of these technologies, taking into account the anticipated demand growth until 2060 [2], carbon footprint, scrap availability and recycling, and integration of CCS. Figure 1 shows the yearly and cumulative C-emissions from business-as-usual (BAU), best available technology (BAT), BAT with integrated CCS and enhanced recycling (CCS+Recyc), low penetration of zero-carbon technologies (Low-C), complete decarbonisation by 2060 (Zero-C) scenarios compared with the IEA-2DS and IEA-B2DS targets. It is evident that BAT and BAU will far surpass the C-budget, whereas CCS+Recyc is only able to satisfy the IEA-2DS targets. Low-C and zero-C scenarios are able to B2DS targets in the later years, however, no scenarios was able to meet the cumulative C-budget for IEA-B2DS, suggesting the need for even more aggressive phasing out of C-intensive routes.

Achieving the IEA-2DS and B2DS emissions targets for the steel industry is not possible through retrofitting existing plants and efficiency improvements. The transition would need massive changes to our steel making infrastructure. Through this work, we wish to highlight the urgency required in completely decarbonising of the steel industry within the next 40–50 years.

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*Contact email: mahesh.venkataraman@anu.edu.au

Ni-Fe-P Nanoparticles Embedded in N-Doped Carbons as Highly Effective and Stable Electro-Catalysts for Water Splitting (Pumped Hydro, Hydrogen and Other Storage Technologies)

Yang Wang[1], Dongyuan Zhao[1, 2], Cordelia Selomulya[1] and Huanting Wang[1]

[1] The Department of Chemical Engineering, Monash University, Clayton, Australia

[2] Collaborative Innovation Center of Chemistry for Energy Materials (iChEM), Department of Chemistry, Laboratory of Advanced Material, Fudan University, Shanghai, China

Hydrogen production from water by electrolysers which are assembled based on non-precious catalysts, is highly desirable but still challenging due to their inferior catalytic performance compared with noble metals. Thus, strategies remain to be needed to design effective non-noble electro-catalysts with high performance. Herein, we develop a synthesis strategy combining Prussian blue analogue (PBA) based ion-exchange with low-temperature annealing. By employing this strategy, hierarchical nanotubes composed of Ni-Fe-P nanoparticles and N-doped carbon on nickel foam (Ni-Fe-P@NC/NF) are synthesized as a robust electro-catalyst for both oxygen evolution reaction (OER) and hydrogen evolution reaction (HER) in overall water splitting.

The as-synthesized Ni-Fe-P@NC/NF requires only a very low over-potential of 220 mV to reach a current density of 50 mA cm^{-2} for OER and just 65 mV to obtain 10 mA cm^{-2} for HER. Additionally, when being used as a bifunctional catalyst for overall water splitting, the assembled electrolyser needs an ultralow cell voltage of 1.49 V to reach 10 mA cm^{-2} with extremely excellent durability for 100 h, among the best-performing overall-water-splitting electrolysers reported to date. The extraordinary performance of Ni-Fe-P@NC/NF might be attributed to the abundant unsaturated active sites from Ni-Fe-P nanoparticles of low crystallinity, the high conductivity of N-doped nano-carbons, the well-defined hierarchical nanotube structure with large surface area and the synergistic effect between Ni-Fe-P nanoparticles and N-doped carbons.

Therefore, our strategy of PBA-based ion-exchange plus low-temperature annealing method can inspire to develop other new active multi-metallic catalysts for water splitting by varying the metal oxide precursors before ion-exchange or applying different annealing methods such as sulfuration or selenization, as well as for other electrochemical reactions such as CO_2, N_2 reduction reaction or methanol oxidation reaction.

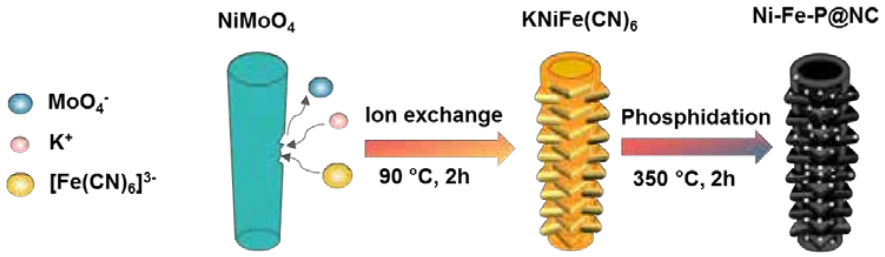


Figure 1: Schematic illustration of the synthesis process of Ni-Fe-P@NC nanotubes

* Contact email: daisywy91@gmail.com, daisy.wang@monash.edu

† Group URL: https://sites.google.com/site/huantingwangroup

COSTS AND BENEFITS OF DEMAND-SIDE RESPONSE ARE DISTRIBUTED UNEVENLY ACROSS SOCIODEMOGRAPHIC GROUPS (Demand Response)

L. V. White [1,2*] and N. D. Sintov[1]

[1] The Ohio State University School of Environment and Natural Resources, Columbus OH, US

[2] The Australian National University College of Asia and the Pacific, Canberra, Australia

Demand-side response (DSR) measures are gaining prominence as a way to integrate renewable generation into electric grids, and are poised for implementation among millions of households in the near future. However, it is unclear whether the costs and benefits of DSR are distributed equally across sociodemographic groups. This work examines the impacts of DSR (i.e., electricity use and bills; personal health) on vulnerable groups, defined as those that have limited means to meet energy costs, are underrepresented in energy decision-making, and/or may suffer negative health consequences if energy use is curtailed. Specifically, we examine households vulnerable on indicators of low income, elderly age, physical disability, Hispanic ethnicity, and African American race. Our sample comprises 6358 households that participated in a pilot time-of-use (TOU) program administered by a power utility in the southwestern US. Households were randomly assigned to either TOU or control rates. Among households on TOU rates, although low-income and Hispanic households report greater efforts to curtail use than their non-vulnerable counterparts, they achieve smaller on-peak use reductions. The elderly see significantly higher bills on TOU compared to baseline than non-elderly households. Irrespective of TOU assignment, households vulnerable on low-income, disability, and Hispanic indicators report greater frequency of discomfort and likelihood of needing medical attention. TOU does not alleviate this burden, and for some households (i.e., disability) exacerbates it. Overall, vulnerable households benefit less and bear greater burdens under TOU, stressing a need for more caution in the design and rollout of DSR programs.

* Contact email: white.3110@osu.edu

Incorporating Operational Flexibility for an Optimal Renewable Grid (Energy Systems Optimization)

Semini Wijekoon[1], Ariel Liebman[1], Simon Dunstall[2]

[1] Faculty of Information Technology, Monash University, Caulfield East, Victoria, Australia

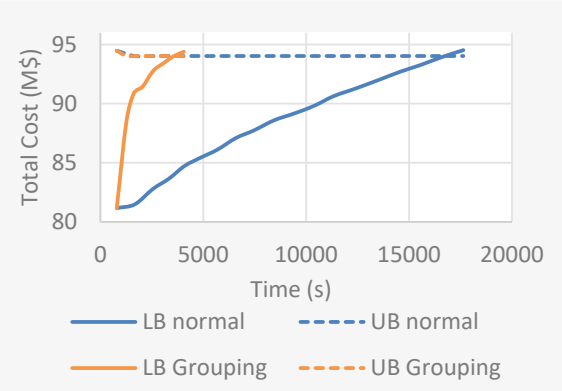
[2] Data 61 CSIRO, Docklands, Victoria, Australia

With high penetration of variable renewable generation, planning for operational flexibility along with generation and transmission capacities has become an important aspect to ensure reliability of a system [1]. While there are multiple methods to attain flexibility, most common approaches can be listed as flexible generators such as gas units and energy storage systems (ESS) such as large-scale battery or pumped hydro, as they can respond instantly to rapid variations in renewable generation, to avoid load or renewable curtailment.

To accurately represent operational flexibility in planning problems, the embedded operational model must be the unit commitment (UC) formulation [2]. As UC takes temporal variations in load and renewable generation into account, technical limitations such as start-up cost, minimum generation, ramping limits, minimum up and down times, charging and discharging limits can be modelled with great precision. However, UC is often avoided in planning problems due to its complexity (large numbers of binary variables and inter-temporal constraints), and economic dispatch (ED) that ignores operational flexibility is used instead.

In this study, we attempt to quantify the error between ED and UC in planning context and find the trade-off between improvement in accuracy and increase in computational complexity. For that we solved the planning problem considering both ED and UC. As planning problems with UC are computationally limited, we developed a tractable framework based on an existing scenario decomposition (SD) approach [3] to reduce the computational time, where each day/week solved independently to generate potential solutions. To further reduce the computational time, a grouping algorithm that groups dissimilar scenarios was also introduced. As shown in the figure, the algorithm shows significant improvement in computational efficiency. We utilized a modified 14-bus system [4] for a period of one year to analyse the impact of operational flexibility.

Although consideration of UC in planning problems is computationally expensive, we observed that ignoring flexibility could lead to sub-optimal generation mix due to underestimation of operational cost. When the solution obtain from ED is simulated with UC to find the true operational cost, the total cost turned out to be higher than the solution obtained from UC model. Even though this difference is not significant in a small test case like 14 bus system, the difference could be substantial in larger systems.



Op. Model	ED	UC
Obj. (M$)	636.74	643.64
Diff. (%)	1.07%	-
Time(s)	2421	96098
Inv. Cost (M$)	186.71	177.13
Op. Cost (M$)	450.02	466.513
Solution	2 Coal, 1 OCGT, 2 Wind, 2 Solar, 5 Lines	2 Coal, 1 OCGT, 2 Wind, 1 Solar, 5 Lines
UC Sim. (M$)	644.62	-
Diff. (%)	0.15%	-

Table 1 Results

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Contact email semini.wijekoon@monash.edu

DELEGATES (AS ON 18 JUNE 2019)

Emma Aisbett
Kate Auty
Chris Baker
Hugo Batten
Fiona Beck
Lisa Beckmann
Rohan Best
Sara Bice
Lachlan Blackhall
Steve Blume
Rohan Borah
Olivia Boyd
Kerryn Brent
Courtney Bryant
Natasha Cannistra
Rowena Cantley-Smith
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Chunguang Tang
Danny Tantri
Colin Thomas
Kim van Netten
Mahesh Venkataraman
Yang Wang
Chris Waring
Lee White
Tom White
Paul Wyrwoll

CONTACT US

For more information
contact ERICA Chair 2018/19:

Professor Kenneth Baldwin
Director, Energy Change Institute
The Australian National University
E kenneth.baldwin@anu.edu.au
T +61 (0)2 6125 4702

Sarah Wilson
Communications Manager,
Energy Change Institute
The Australian National University
E sarah.wilson@anu.edu.au
T +61 (0)478 563 281

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