THE UNIVERSITY OF MELBOURNE

Melbourne Energy Institute

MELBOURNE ENERGY INSTITUTE

ANNUAL REPORT 2020

CONTENTS

EDITOR

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MESSAGE FROM THE DIRECTOR

We made it through an extraordinary 2020. Keeping ourselves safe whilst our organisations transformed overnight and continued to function was a remarkable achievement.

I am most grateful to the dedicated support of the entire MEI team in this regard. Particularly all our colleagues who home schooled young children over the year. As if having little kids and a day job during normal times isn't hard enough! Sincere thanks also to the attendees of MEI's many virtual events, our researchers, and of course our Advisory Board and financial supporters.

You all showed remarkable commitment and generosity.

Today, I sit in my study at home on the last day of our latest lockdown. A mild summer is ending, and with working from home and record renewables, 2020 was also a standout for our energy system. Quarter 4's electricity demand was its lowest quarterly average since 2001, and electricity prices continued to fall significantly from highs of a couple of years ago.

But we needn't just talk about electricity. How often did you visit the petrol station last year? And what does that tell us about the prospects for transport sector abatement via remote work?

Zoom also demonstrated, yet again, how globally connected we are. Many of us have family, friends and collaborators who have suffered greatly from COVID-19. Right now, some are also experiencing a bitter winter that is also impacting their energy systems. Notably, Texas is experiencing minimum temperatures that occur somewhere between once in 10 to 100 years, with blackouts now rolling across the state.

All proof that we aren't the only country whose energy system is deeply challenged by extreme weather, and of our need to collaborate across borders as well as disciplines on these wicked energy problems.

MEI is therefore proud to have supported the launch of several, deeply collaborative efforts in 2020.

The University's *ARC Training Centre in Optimisation Technologies, Integrated Methodologies, and Applications* will work with our colleagues at Monash University and several industry and international partners, and is led by Prof. Kate Smith-Myles of the Faculty of Science. The *Ford Motor Company* expanded our collaboration to include the quantum computing research of Prof. Lloyd Hollenberg. And the *Affordable Heating and Cooling Innovation Hub* commenced its work with Australian industry, CSIRO, and our own Dr. Brendan McNiven of Architecture, Building and Planning and Prof. Lu Aye of the School of Engineering.

I encourage you to read more about such initiatives in this *Annual Report* and wish you good health and happiness for the year ahead.

All the best,

Michael
Prof. Michael Brear, FTSE, FCI, FIEAust
Director, Melbourne Energy Institute
February 17th, 2021

THE MELBOURNE ENERGY INSTITUTE

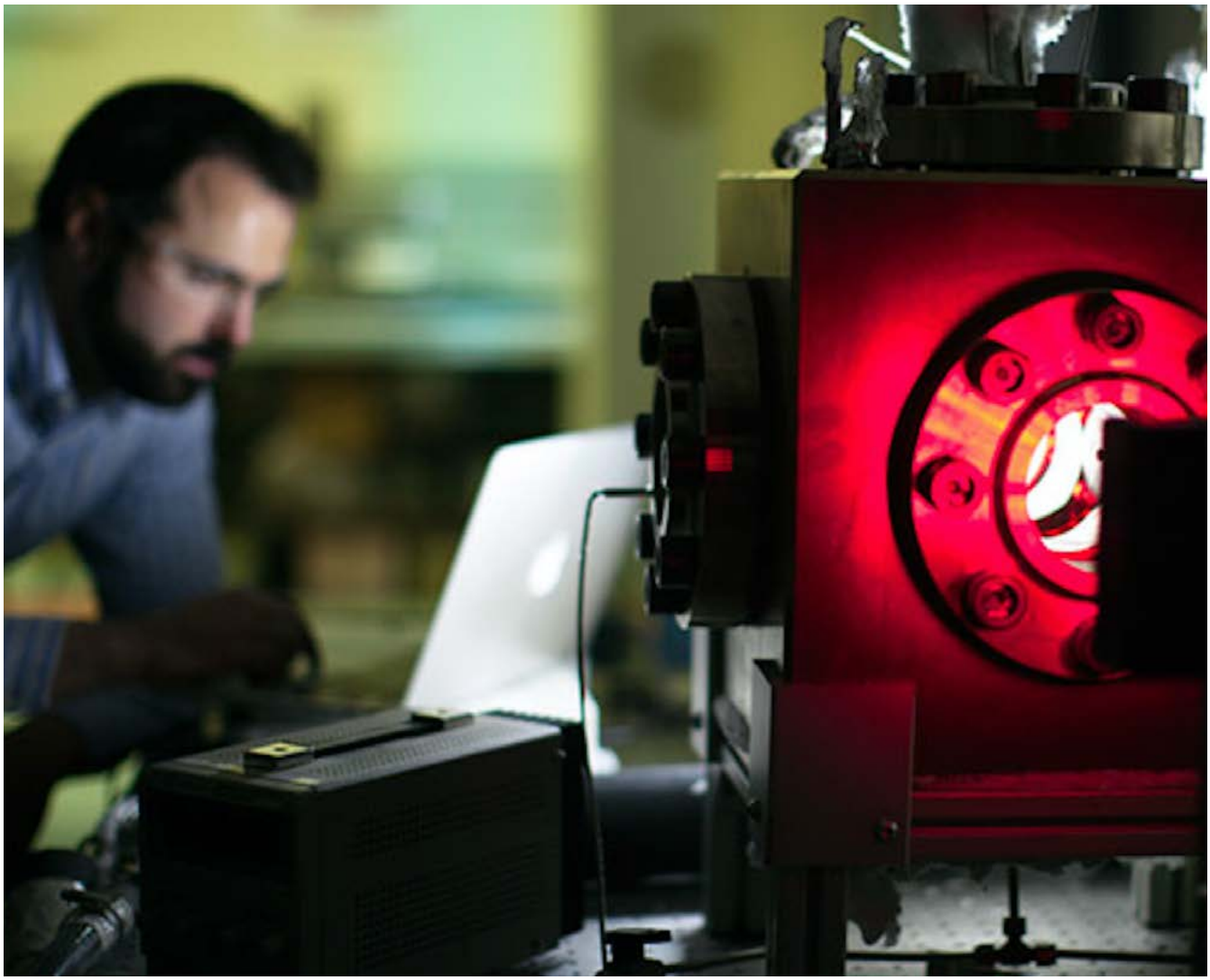
The Melbourne Energy Institute (MEI) delivers influential, interdisciplinary research on the transition to a clean energy system. We work with the community, industry and government on some of the world's most pressing energy challenges.

The University of Melbourne undertakes world-leading research in many disciplines. It has the largest research expenditure of any Australian university, and the largest cohort of research students in Australia.

MEI has over 300 specialists across Architecture, Economics, Engineering, Health, Law, Planning, Science and Social Science. They include a former Chief Scientist of Australia, several recipients of Australia Day Honours, several Fellows of Learned Academies and numerous Fellows of Professional Societies.

MEI researchers work together in four programs:

- Energy Systems
- Hydrogen and Clean Fuels
- Power Generation and Transport
- Environment and Resources



THE MEI TEAM

MEI is run by a team of dedicated staff who look after the Institute's external and internal engagement and research programs.

Professor Michael Brear
FTSE, FCI, FIEAust
Director

Ms Anita La Rosa
Institute Manager

Ms Kine Asgautsen
Marketing and Communications Coordinator

Ms Chloe Mumford
Administration and Events Assistant

Associate Professor Terry Jones
Enterprise Senior Fellow and Project Manager

Professor Pierluigi Mancarella
MEI Program Leader Energy Systems, and Chair Professor of Electrical Power Systems

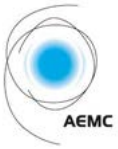
Associate Professor Kathryn Mumford
MEI Program Leader Hydrogen and Clean Fuels, Associate Professor in the Department of Chemical Engineering

Professor Richard Sandberg
MEI Program Leader Power Generation and Transport, Chair of Computational Mechanics and ARC Future Fellow

Dr Robyn Schofield
MEI Program Leader Environment and Resources, Senior Lecturer, and Director of the Environmental Science Hub

OUR PARTNERS

MEI is proud to work alongside our industry and government partners. Collaborative research and knowledge transfer are central to MEI's work, and we welcome new partners.



HIGHLIGHTS OF 2020

IMPROVED FORECASTING FOR AUSTRALIAN WIND FARMS

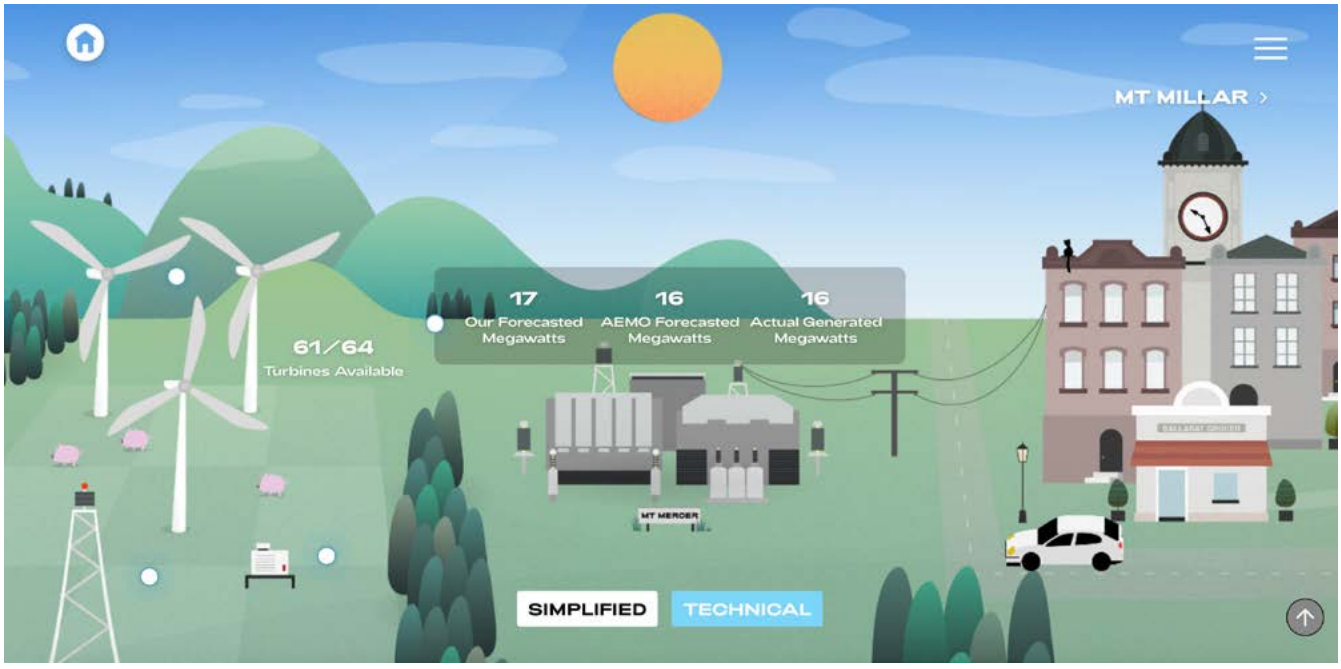
Wind is a fantastic source of renewable energy, but it is variable and can be hard to forecast. As renewables become dominant, we're presented with the challenge of more accurately forecasting renewable energy production. We need to maintain a secure and efficient electricity system over the energy transition.

In March 2019, Meridian Energy Australia (MEA) and the University of Melbourne won support from the Australian Renewable Energy Agency (ARENA) to develop improved, real-time forecasts of wind farm power generation. Until recently, the Australian Energy Market Operator (AEMO) forecasted the generation from all the wind and solar farms across the National Electricity Market (NEM). Using this ARENA support, the team from MEA and the University have developed and implemented their own wind forecasting system and integrated this into AEMO's real-time processes for managing the NEM.

More accurate forecasting of renewables helps their uptake in the NEM. It also supports AEMO to maintain system security while reducing total emissions and costs. Asset owners and operators are also well placed to understand how an asset should perform, and the NEM rewards wind farm owners financially for improved wind farm forecasting.

The team from MEA and the University have also created an interactive website for the wider community. This website is open for anyone to access, and is an educational resource for primary, secondary and tertiary students as well as the general public. Our hope is that this site builds community understanding of renewables and the prospects of a secure and decarbonised energy system. Read more about this exciting project.

https://energy.unimelb.edu.au/news-and-events/news/improved-forecasting-for-australian-wind-farms



MEI SUPPORTS THE AEMC FRAMEWORK TO ENHANCE POWER SYSTEM RESILIENCE

While secure power system operation under normal conditions is traditionally associated with the concept of reliability, the system's ability to respond to so-called high impact, low probability (HILP) events, is associated with the emerging concept of *resilience*.

Professor Pierluigi Mancarella, leader of the MEI's Energy Systems Program, recently supported the Australian Energy Market Commission (AEMC) in their review of the South Australian Black System event of September 2016 and their development of new mechanisms to enhance power system resilience.

The AEMC's report was published in December 2019 following extensive work over the year. It provides a series of recommendations to extend current technical and regulatory practices for secure system operation under normal conditions such that extreme conditions can also be accommodated. Such conditions, which might lead to cascading failures and eventually even to a system black, could be caused by bushfires, extreme weather or other events, as the National Electricity Market has experienced this summer.

The conceptual foundation for the resilience framework proposed by the AEMC is based on Professor Mancarella's earlier work, including "The Grid: Stronger, Bigger, Smarter? Presenting a Conceptual Framework of Power System Resilience", published in the IEEE Power and Energy Magazine in 2015.

This work for the AEMC is in addition to the support MEI recently provided to the Australian Energy Regulator's (AER's) Review of the Value of Customer Reliability (VCR); a quantity that is intended to reflect the value that different types of customers place on the reliable supply of electricity.

A rigorous approach to power system resilience and the VCR is very important because they are at the heart of the energy trilemma. Investment in network or generation assets may lead to greater resilience or reliability, but also higher energy costs. Investment in renewable generation reduces emissions, but it may also reduce resilience or reliability. Read more about this important work.

https://energy.unimelb.edu.au/news-and-events/news/mei-supports-the-aemc-framework-to-enhance-power-system-resilience

ADAPTING TRAFFIC/ROUTE OPTIMISATION PROBLEMS TO THE QUANTUM COMPUTER FRAMEWORK: A PARTNERSHIP BETWEEN FORD AND THE UNIVERSITY OF MELBOURNE

Quantum computers are potentially far more powerful than conventional computers and may enable the solution of many problems that are currently intractable. After sustained research over decades, quantum computers are now emerging from the laboratories of companies such as IBM and Google.

A University of Melbourne team, led by Professor Lloyd Hollenberg, has been working in quantum computing for over 20 years. The IBM *Q Hub* at the University of Melbourne was established in 2018, providing University researchers with access to IBM's world leading quantum computer hardware and software. Using these facilities, the University team has developed expertise in the conversion and implementation of problems for solution on quantum computer hardware.

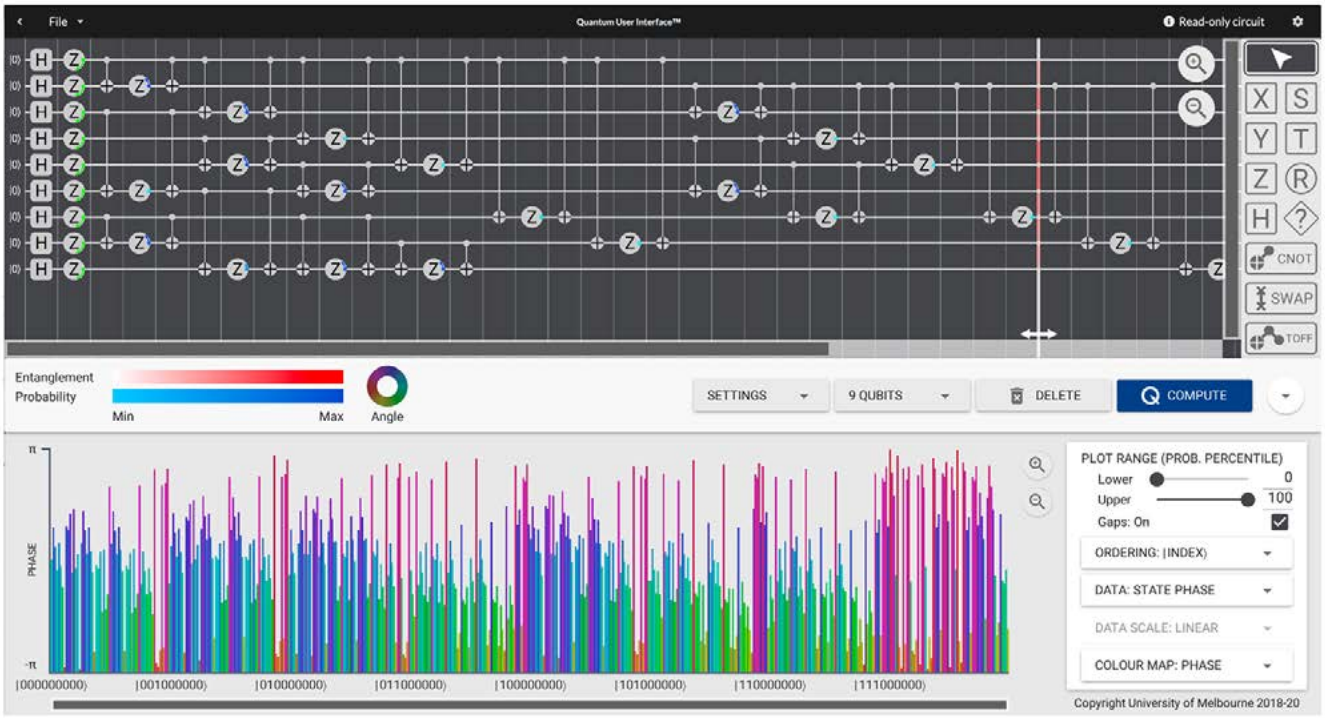
Acknowledging the potential of quantum computing, Ford Motor Company has partnered with the University to examine how it might be applied to a variety of combinatorial optimisation problems involving traffic optimisation and fleet routing. There are several, specific challenges involved in doing this.

These include devising quantum approaches to traffic/route problems, mapping these to optimal quantum circuits and constructing error-mitigation schemes for simulation and implementation under realistic hardware conditions.

Solution of such problems offers major benefits. For example, it could enable deep reductions in a fleet's fuel consumption and emissions of greenhouse gases and other pollutants, whilst reducing traffic congestion and enabling much more interaction with intelligent vehicles. It is therefore strategically important for companies like Ford to be "quantum ready", i.e. to understand how to apply quantum computing and work in tandem with technology developments such that they will be able to influence and drive this technology to advantage in their sector. Of course, as the ICT industry adapts to quantum computing technology, there will also be flow-on benefits to society via the solution of problems of comparable complexity in a range of areas.

The University and Ford have been close collaborators for decades. In recent years, their collaboration has broadened to include research on quantum computing, advanced materials and advanced propulsion systems and clean fuels.

Learn more about this work.
https://energy.unimelb.edu.au/news-and-events/news/adapting-trafficroute-optimisation-problems-to-the-quantum-computer-framework-a-partnership-between-ford-and-the-university-of-melbourne



ENVIRONMENTAL PERFORMANCE IN CONSTRUCTION (EPIC) DATABASE

Whilst buildings account for close to 40% of national energy demand and greenhouse gas emissions, there are also significant embodied energy and emissions associated with their construction. These embodied quantities are the sum of the energy and emissions required to produce and assemble all the materials used whilst the building is constructed.

The embodied energy and emissions of construction projects is increasing, especially as our projects become more material and technologically intensive and as we reduce building operational energy demands. Recognising the need to assess these indirect embodied environmental effects of construction projects, Associate Professor Robert Crawford led the Environmental Performance in Construction (EPiC) initiative; a multi-institutional research project funded by the Australian Government through the Australian Research Council.

This form of data has been quite limited in Australia, so the focus of Associate Professor Crawford and his team's research was developing a database of embodied energy and GHG emissions coefficients for the production of construction materials. Manufacturer data on energy demand and greenhouse gas emissions for the production of a range of construction materials was combined with industry-based energy and emissions data from national accounts. This produced coefficients representing the total energy and emissions associated with the production of these materials from cradle to factory gate.

The result of the team's research and data collection is the EPiC Database, a comprehensive source of embodied energy and emissions values for construction materials produced in Australia. It uses a novel hybrid approach to compile the coefficients to ensure data completeness, which is rare in similar international databases. The data is presented in an accessible format for use by industry.

Find out more about the EPiC database.
https://energy.unimelb.edu.au/news-and-events/news/environmental-performance-in-construction

ADVANCED PLANNING OF PV-RICH DISTRIBUTION NETWORKS

Over the last twenty or so years, residential solar PV has grown from a technology loved by a few early adopters to one that is embraced by many Australians. Whilst this extraordinary growth has brought significant environmental and economic benefits, challenges associated with the integration of residential solar PV into local electricity distribution networks have also become more significant. Indeed, determining the limit on how much more solar PV we can put on our roofs without compromising power system operation is a technically complex problem.

With support from the Australian Renewable Energy Agency (ARENA), the Melbourne Energy Institute and AusNet Services have been examining this solar PV 'hosting capacity' problem. The team, led by Professor Nando Ochoa of the University's Department of Electrical and Electronic Engineering, have first developed high fidelity distribution network models to assess residential solar PV hosting capacity by using large amounts of measured network and customer data.

The latest report on their ARENA project, Advanced Planning of PV-Rich Distribution Networks, focuses on more traditional approaches to raising solar PV hosting capacity and the so-called *Volt-Watt and Volt-var settings* that were mandated in Victoria in late 2019.

This report finds that the new *Volt-Watt and Volt-VAr settings* can have significant benefits for both customers and the network. Voltage issues and the resulting curtailment of solar PV can be reduced, enabling at least 20% of residences within the same network to have solar PV. When complemented by traditional approaches to increasing hosting capacity, including careful setting of existing network assets or targeted network augmentation where required, the solar PV hosting capacity can be raised to about 40%. Significantly higher hosting capacities may even be possible if certain technical requirements are relaxed; something that we should be able to evaluate as residential solar PV continues to grow.

Current research by the MEI /AusNet team is now focused on non-traditional approaches that promise even higher hosting capacities. The use of more advanced and controllable solar PV inverters, voltage regulation devices and battery energy storage systems will all be examined.

Find out more about this project and the MEI's partnership with AusNet and ARENA.

https://energy.unimelb.edu.au/news-and-events/news/advance-planning-of-pv-rich-distribution-networks

USING QUANTUM COUPLED STATES TO IMPROVE SOLAR CELL EFFICIENCY

Today, almost all solar cells deployed on our roofs and at solar farms are made from silicon. However, these cells only use a fraction of their incident sunlight efficiently. Whilst most of the energy in the 'red' part of the solar spectrum is turned into electricity, about 60 to 80 percent of the yellow, green and blue parts of the spectrum is lost as heat.

These issues can be overcome by stacking 3 to 4 solar cells that are tuned to different colours of light on top of one another, with each cell harvesting different parts of the solar spectrum more efficiently. However, this comes at a high price. We therefore need simpler and more cost-effective ways to recover this otherwise lost energy and turn it into electricity.

A curious feature in some materials is that when a single photon of high energy light is absorbed, two or more excited states at lower energy are created. This process is called *multiple exciton generation* (MEG). A team lead by Dr David Jones has been developing new organic semiconductor materials that exploit this property in order to develop high efficiency, lower cost solar cells.

Dr Jones' team has shown that we can potentially double the power output of a solar cell via absorbed yellow, green or blue light, increasing its theoretical efficiency from about 32% to 44%. This means that a 20% reduction in the cell's cost per unit of delivered power is prospective.

Further progress is dependent on the development of new materials that enhance the efficiency of the MEG process. This, in turn, requires researchers to understand and exploit fundamental quantum mechanical properties of organic semiconductor materials. In support of these efforts, Dr Jones has recently received support from the Australian Renewable Energy Agency (ARENA) to examine a class of materials that improve silicon solar cell efficiency in this way.

Read more about this project, which will be completed in collaboration with the University of Queensland and the Australian National University.

https://energy.unimelb.edu.au/news-and-events/news/using-quantum-coupled-states-to-improve-solar-cell-efficiency

PERFORMANCE OF WHOLESALE ELECTRICITY MARKETS WITH HIGH WIND PENETRATION

Electricity markets around the world have added significant Variable Renewable Generation (VRG) in the form of wind and solar. As well as having zero greenhouse gas emissions, these technologies have limited predictability, variable output and low operating costs. Some form of policy is also usually used to encourage investment in VRG, such as the various renewable-specific policies that are currently in place across Australia or our discontinued carbon price. However, the economic performance and investibility of wholesale electricity markets with high levels of VRG is not clear, particularly when we consider realistic levels of renewable generation uncertainty.

In a paper recently published in Energy Economics, MEI researchers examined the performance of a wholesale electricity market with increasing wind penetration. The conditions that determine investibility for new generation are identified, and the effectiveness of renewable-specific and carbon-based policies are examined.

Comparison is first made to the canonical result that competitive marginal pricing should induce investors to build the optimal mix of generation via market signals alone. This is the fundamental theoretical basis on which 'energy-only' markets, like Australia's National Electricity Market (NEM), rely to send investment signals to generators to enter or leave the market. It is not obvious that this result will always hold in renewable-rich systems for several reasons.

To do this, the impact of either a VRG incentive and a carbon price is first considered in the generation planning problem. The resulting generation fleets are then subjected to unit commitment that considers lumpiness of investment and VRG forecast uncertainty, followed by conventional economic dispatch of the committed units.

For wind penetrations up to approximately 50% by annual energy, it is found that unit commitment and renewable generation forecast uncertainty do not cause significant departure from this canonical economic result if the generation fleet is 'optimal'. Optimality in this sense is determined in the planning problem that did not feature unit commitment, and which allows thermal generators to be built or retired as greater renewable generation or abatement was mandated. In contrast, the wholesale market with a fixed thermal fleet experiences progressively lower rates of returns to thermal generators as the level of renewable generation and/or abatement increased. This is simply because of over-capacity, with subsidised new wind and lack of capacity exit depressing wholesale market prices.

Read more about how these results have implications for planning studies and market design.

https://energy.unimelb.edu.au/news-and-events/news/performance-of-wholesale-electricity-markets-with-high-wind-penetration

MEI RESEARCH PROGRAMS

ENERGY SYSTEMS

The Energy Systems Program considers how different energy technologies interact with one another and society. The program includes the technical and economic analysis of energy networks, wholesale and retail energy markets, and energy system planning.

CAPABILITIES

- Energy network, system and market integration of renewable energy sources
- Distributed energy resources and smart grids
- Integrated energy networks and multi-energy systems
- Risk and resilience assessment of future energy systems
- Demand modelling using randomised control trials, big data and machine learning
- Retail energy markets and consumer behaviours control trials, big data and machine learning

IMPACT

- Modelling work commissioned by the Finkel Review
- AEMO demand and reserves forecasting using AMI data and machine learning approaches
- Modelling of electricity consumer behaviour for Billcap, Click Energy and Simply Energy
- Collaborations with AEMC and AER on power system resilience and reliability

RESEARCH CENTRES

- Centre for Market Design
- Power and Energy Systems

KEY RESEARCHERS

Program Leader: Professor Pierluigi Mancarella
Professor Lu Aye
Professor James Bailey
Professor Howard Bondell
Professor Michael Brear
Associate Professor David Byrne
Dr Sangeetha Chandra-Shekeran
Associate Prof Robert Crawford
Professor Rob Evans
Professor John Freebairn
Professor Ross Garnaut
Professor Fiona Haines
Professor Glenn Hoetker
Associate Professor William Ho
Associate Professor Terence Jones
Professor Chris Leckie
Professor Pierluigi Mancarella
Professor Chris Manzie
Dr Leslie Martin
Professor Brendon McNiven
Associate Professor Monica Minnegal
Dr Reihana Mohideen
Professor Nando Ochoa Pizzali
Dr Behzad Rismanchi
Professor Prakash Singh
Professor Kate Smith-Miles
Professor Doreen Thomas
Dr Maria Vrakopoulou

HYDROGEN AND CLEAN FUELS

The Hydrogen and Clean Fuels Program integrates research into production, distribution and use of hydrogen in the energy system. The program studies electrolysis and clean fuel production, as well as hydrogen and clean fuel distribution and use in industrial and transport applications.

CAPABILITIES

- Process engineering and techno-economics of hydrogen production from renewables and fossil fuels with carbon capture and storage (CCS)
- Advanced gas turbine and reciprocating engine systems running on hydrogen and hydrogen-derived fuels
- Assessment of hydrogen integration into the natural gas network, including Power to Gas (P2G) concepts
- Catalysis and process engineering of converting hydrogen to clean liquid fuels
- Sub-surface storage of hydrogen

IMPACT

- Reciprocating engine research with hydrogen and synthesis gas fuelling for Caterpillar, Ford and other partners
- Support to the Council of Australian Government's (COAG) National Hydrogen Strategy
- Provision of expert advice to the Hydrogen Energy Supply Chain (HESC) project
- Optimisation of integrated energy systems featuring hydrogen for the Future Fuels CRC and other partners

RESEARCH CENTRES

- Advanced Separation Technologies Group
- Clean Energy Laboratory
- Peter Cook Centre for CSS Research
- Scholes Research Group
- Thermodynamics Laboratory

KEY RESEARCHERS

Program Leader: Associate Professor Kathryn Mumford
Professor Robin Batterham
Professor Michael Brear
Dr Robert Gordon
Dr Eirini Goudeli
Professor Ralf Haese
Professor Sandra Kentish
Dr Gang Li
Professor Pierluigi Mancarella
Professor Paul Mulvaney
Associate Professor Colin Scholes
Professor Geoff Stevens
Dr Mohsen Talei
Associate Professor Yi Yang

POWER GENERATION AND TRANSPORT

The Power Generation and Transport Program brings together researchers who investigate several forms of renewable and low emission power plants for stationary and mobile applications. This includes advanced wind, solar, gas turbine, reciprocating engine and energy storage technologies.

CAPABILITIES

- Carbon Capture and Storage
- Conventional and alternative fuels and emissions chemistry
- Gas turbine, reciprocating engine, hybrid and electric powertrain dynamics and optimisation
- Wind turbines/farms, solar PV and energy storage dynamics and optimisation
- Low drag vehicles for land, sea and air
- Materials for advanced photovoltaics, displays, lighting, and high temperature applications
- Advanced computational methods and machine learning in energy applications

IMPACT

- Energy efficient lighting for CSIRO and partners
- Propulsion, engines and fuels for Ford, DST Group and MHI
- Improved aircraft engine aerodynamics for General Electric
- High temperature material for the Australian Defence Force
- Modelling of real-world, solar PV performance across Australia with AEMO
- Operational forecasting of wind and solar farm power generation with Meridian Energy Australia and others

RESEARCH CENTRES

- ARC Centre for Exciton Science
- Fluid Mechanics Group
- Peter Cook Centre for CSS Research
- Thermodynamics Laboratory
- Victorian Organics Solar Cell Consortium

KEY RESEARCHERS

Program Leader: Professor Richard Sandberg
Professor Robin Batterham
Professor Michael Brear
Dr James Bullock
Professor George Franks
Dr Robert Gordon
Dr Eirini Goudeli
Professor Lloyd Hollenberg
Dr David Jones
Professor Sandra Kentish
Dr Patricia Lavieri
Professor Dan Li
Professor Chris Manzie
Professor Jason Monty
Professor Paul Mulvaney
Associate Professor Guillermo Narsilio
Dr Behzad Rismanchi
Professor Geoff Stevens
Dr Mohsen Talei
Dr Claire Vincent
Professor Rachel Webster
Dr Wallace Wong
Associate Professor Yi Yang

ENVIRONMENT AND RESOURCES

The Environment and Resources Program examines the interactions between our energy systems and the environment. This program includes energy resource extraction and use, and how current energy systems influence environmental and human health, including legal and economic implications.

CAPABILITIES

- Air quality and health impacts
- Environmental chemistry and fluid dynamics
- Geology and geochemistry of oil, gas and other basin resources including carbon capture storage
- Modelling of the carbon cycle and climate change
- Resource economics
- Resource law

IMPACT

- Deepen our understanding and minimise uncertainties in geological carbon storage for CO2CRC, ANLEC R&D and BHP
- Determine anthropogenic trace gas distribution and residence time to inform UNFCCC processes
- Model the consequences of nations' energy policies to inform governments and UNFCCC
- Measuring and forecasting air pollutants in cities to inform urban design and policy development

RESEARCH CENTRES

- Centre for Market Design
- Centre for Resources, Energy and Environmental Law
- Clean Air and Urban Landscapes Hub
- Melbourne School of Population and Global Health
- Peter Cook Centre for CSS Research

KEY RESEARCHERS

Program Leader: Dr Robyn Schofield
Professor Robin Batterham
Dr Sangeetha Chandra-Shekeran
Professor Peter Cook
Professor Michael Crommelin
Professor Shyamali Dharmage
Professor John Freebairn
Professor Ross Garnaut
Professor Lee Godden
Professor Ralf Haese
Professor Fiona Haines
Dr Leslie Martin
Professor Stephan Matthai
Associate Professor Monica Minnegal
Professor Jason Monty
Associate Professor Kathryn Mumford
Professor Peter Rayner
Professor Mike Sandiford
Professor Mark Stevenson
Professor Doreen Thomas
Dr Claire Vincent

STUDENTS OF MEI

Supporting early career researchers is a central part of MEI's growth. The Institute has a strong belief that in fostering the ambitious talent of early career researchers, we can help them become future thought leaders in the energy sector.

MEI INTERNSHIP PROGRAM

The MEI Internship Program offers 12 week paid internships for talented people who want to help drive the energy transition. The program pairs interns with leading researchers in industry and academics across several faculties to work on exciting energy related projects. Examples of internship projects include:

- Organisational determinants of the uptake and performance of energy efficiency initiatives
- Using renewable hydrogen in gas turbines
- Combustion chemistry of hydrogen-natural gas mixtures
- Online integrated electricity-gas-hydrogen network modelling tool with advanced input-output graphical user interface
- Machine-learning for improving efficiency of power generation
- Decarbonising the transport sector with renewable hydrogen
- Forecasting techniques for renewable energy sources: performance analysis and economic impact on grid operation
- Design of advanced input-output and data analytics graphical user interface for a low-carbon power system operation and planning tool
- Mapping methane hot-spots from space with novel retrieval data
- Gippsland geothermal mapping and cost analysis tool — information gathering and geothermal economic algorithms
- Quantum information for fusion power

SPOTLIGHT ON A STUDENT

MEI has numerous talented graduate students working on important energy projects. Meet some of our wonderful students whose work is contributing to a more sustainable energy transition.

Mathieu Pichault is a PhD student undertaking research under the joint supervision of academic staff in Earth Sciences and Mechanical Engineering. His research involves detecting and forecasting wind power ramps at the wind farm scale to optimise the integration of wind farms into the grid.

Ceren Ayas is undertaking a PhD in the School of Social and Political Sciences, and is affiliated with the Climate and Energy College and the Sustainability Science Lab. Her research focuses on how justice can facilitate low-carbon transition.

Will Clarke completed his PhD under the joint supervision of academic staff in Mechanical Engineering and Electrical and Electronic Engineering. His research examined the impact that solar PV, wind and energy storage have on the development of advanced control systems for isolated microgrids.

Sareh Naji completed her thesis under the joint supervision of academic staff in the Department of Infrastructure Engineering and the Faculty of Architecture, Building and Planning. In her research, Sareh conducted building performance optimisations to minimise life cycle costs while maintaining a satisfactory indoor environment.

Érico de Godois Baroni recently completed his PhD in the Department of Chemical Engineering at the University of Melbourne. His research looked at the natural and engineered variations in the physical, biochemical and biological characteristics of algal cells, and how these impact water treatment and the production of renewable fuels and pharmaceuticals.

Lefu (Daniel) Tao has submitted his thesis on the evaluation and screening of adsorbents for the separation of carbon dioxide from natural gas. Lefu has developed a novel and effective method to rapidly evaluate the performance of an adsorbent for CO2 removal from high-pressure natural gas without undertaking expensive trial operations.

Rebecca McQuillan submitted her thesis on the electrochemical regeneration of granular activated carbons *in situ* in Permeable Reactive Barriers. Doing a PhD was never a certainty for Rebecca, but she knew she wanted to pursue something that would make a change in this world for the better, whether that be academia or industry.

James Naughton is undertaking a joint PhD with the University of Melbourne and the University of Birmingham, UK. His PhD focuses on the development of a modelling framework for a Virtual Power Plant (VPP) to unlock the flexibility of renewables and Distributed Energy Resources (DER).

Mostafa Naemi completed his PhD at the University of Melbourne, working under the guidance of Professor Michael Brear and Dr Matthew Jeppesen. His PhD focused on optimal performance of a wind farm with and without battery energy storage.

Paris Hadfield is a PhD candidate in urban planning and geography at the University of Melbourne. She is funded by the Cooperative Research Centre for Low Carbon Living's Future Cities program, and is working under the guidance of Professor Lars Coenen and Professor Chris Ryan. Paris' thesis examines how finance shapes transitions to renewable energy systems in cities.

Michael Liu completed his thesis in October with the Department of Electrical and Electronic Engineering. The aim of his PhD project was to demonstrate the technical feasibility of advanced network management schemes. Michael is currently working at the University of Melbourne as a Research Fellow in the Department of Electrical and Electronic Engineering where he continues with his research.

ENGAGEMENT

MEI runs a vibrant events and communications program that engages with our internal and external key stakeholders. Our events program focuses on the MEI*network*, and we also host numerous public forums with guest speakers from academia, community, industry, and government to discuss critical energy issues.

Despite many of MEI's events being moved to an online format in 2020, engagement with our stakeholders was still very high, with all events attracting a national audience.

MEI*NETWORK*20

The MEI*network* is an annual program that offers education activities related to the energy industry, with an additional focus on professional development and engagement across sector and academic networks. The program provides energy sector professionals and University of Melbourne graduate students with a comprehensive view of the opportunities and challenges that the industry faces.

The success of the MEI*network* is only possible with the generous support of our industry and government partners. We work closely with our partners to develop the program to ensure that it reflects current industry trends and challenges. MEI is grateful to our partners Arup, the Australian Gas Infrastructure Group (AGIG), Powershop, Siemens Energy and the Victorian Government's Department of Environment, Land, Water and Planning (DELWP) for their generous support of the MEI*network*20 program. The following activities took place in 2020 as part of the MEI*network*20 program.

ENERGY SYSTEMS SHORT COURSE

The Energy Systems Short Course was held over three intense weeks in July 2020. Course attendees, including graduate University of Melbourne students and participants from MEI's industry partners, learnt skills in analysing the financial, technical, and environmental performance of energy projects.

MEI received overwhelmingly positive feedback from participants, who said they gained valuable insight into the investment decision-making processes used to determine the viability of different energy investments, and the key components that underpin these decisions.

The Short Course was taught by energy industry expert and University of Melbourne Honorary Professorial Fellow Dr John Burgess, with the assistance of Jonathan Anderson, Senior Engineer at Arup. MEI is grateful to Dr Burgess and Jonathan for their time and dedication to creating a positive and engaging leaning environment whilst adapting the Short Course to a fully virtual delivery model.

ENERGY SYSTEMS SEMINAR SERIES

The Seminar Series aims to give participants a sound understanding of the complete supply and value chain of one of our primary energy vectors. In the 2020 seminars series, attendees were provided with a deep understanding of different discretely delivered energy commodities across seven lectures. Each seminar was delivered by specialists from industry and the University.

MEI SYMPOSIUM 2020

The Melbourne Energy Institute held its third annual Symposium as a virtual event on Friday 11 December 2020. The Symposium showcased research by the University of Melbourne's graduate students, post-docs and academic staff, as well as leading international researchers.

Australia's outgoing Chief Scientist, Dr Alan Finkel AO, delivered the Opening Plenary with his presentation on *Pivoting to the future: the 2020 Low Emissions Technology Statement*. In his presentation, Dr Finkel explored the various technologies aimed at reducing Australia's greenhouse gas emissions, as outlined in the Statement. These priority technologies include clean hydrogen, batteries and pumped hydro storage, carbon capture and storage, measuring soil carbon, and low emission steel and aluminium. He was then joined by MEI Director, Professor Michael Brear, for a discussion on Australia's next steps in pursuing a low-emissions future.

The pre-recorded Plenary was followed by 20 live presentations, including international speakers Professor Mark O'Malley, *University College Dublin*, and Professor Rob Miller FRAeS, *Cambridge University*, and local experts Professor Eric May, *Future Energy Exports*, and Professor of Law Jacqueline Peel, *University of Melbourne*.

The Symposium was divided across MEI's 2020 Research Programs, with prizes awarded to outstanding PhD or PostDoc presenters in each theme:

Energy Systems

Best Presentation

Andrea Vecchi, *PhD Candidate, University of Birmingham and University of Melbourne*
Title: Techno-economic modelling and assessment of the Fishermans Bend Smart Thermal Loop

Power Generation and Transport

Best Presentation

Dr Tom Jelly, *Research Fellow, Mechanical Engineering, University of Melbourne*
Title: High-fidelity investigation of surface roughness effects on heat transfer and drag in gas turbines

Hydrogen and Clean Fuels

Best Presentations (shared prize)

Dr Farzad Poursadegh, *Research Fellow, Mechanical Engineering, University of Melbourne*
Title: An investigation of a directly injected, hydrogen fuelled, heavy duty engine at knock-limited conditions

Dr Mohamed Abdellah, *Research Fellow, Chemical Engineering, University of Melbourne*
Title: Compatibility of plastic pipes with future fuels

Environment and Resources

Best Presentation

Changlong Wang, *PhD Candidate, Climate and Energy College, University of Melbourne*
Title: Australia's opportunity - synergies between hydrogen export and domestic energy transition in Australia

Professor Michael Brear (left) and Dr Alan Finkel AO (right) discussing Australia's next steps in pursuing a low-emissions future during the MEI Symposium 2020 plenary session.

SEMINARS, LECTURES AND WORKSHOPS

ENERGY FUTURES SEMINARS

The Energy Futures Seminars, run in partnership with policy think-tank Grattan Institute, presents a range of views on the immediate and longer-term impacts of energy policy and technological change. Industry experts are invited to present at the seminar, with each event ending with an in-depth audience Q&A.

Energy Futures - Burning gas in a net-zero world?
The Commonwealth Opposition, all state and territory governments, and many businesses are committed to a target of net zero emissions. The Commonwealth has, so far, resisted committing to a 2050 timeline. Whilst almost all the policy and investment focus has been on electricity, representing about a third of Australia's emissions, natural gas contributes almost 20% of Australia's emissions and reducing those emissions looks challenging.

A panel moderated by MEI's *Energy Systems Program Leader*, Professor Pierluigi Mancarella, and comprising Guy Dundas, *Energy Fellow at Grattan Institute*, Lynne Gallagher, *Interim CEO of Energy Consumers Australia*, and Andrew Dillon, *CEO of Energy Networks Australia*, unravelled what this future holds for gas network businesses and consumers and the policy challenges for governments.

AEMO QUARTERLY DYNAMICS WEBINARS

The Australian Energy Market Operator (AEMO) publishes its Quarterly Energy Dynamics report, providing energy market participants, businesses, consumers, governments and the wider energy community with information on the market dynamics, trends and outcomes. MEI was pleased to host AEMO's Dr Jonathan Myrtle, *Team Leader of Market Insights*, for a quarterly webinar to discuss key findings from the latest AEMO report.

Since moving to an online format in 2020, each Quarterly Dynamics webinar has attracted a national audience, with Dr Myrtle facilitating engaging Q&A discussions with participants from industry, government, the community and the University.

Read more about the AEMO seminars here.
https://energy.unimelb.edu.au/news-and-events/news/podcast-aemo-q4-2020-quarterly-dynamics-seminar

LOW-CARBON IRON AND STEELMAKING

Australia exports a large amount of iron ore and metallurgical coal for iron and steelmaking. The advent of renewable steelmaking could have a profound effect on this export business, especially for coal. In January 2020, Honorary Professorial Fellow Dr John Burgess presented a lecture on low-carbon steelmaking, including on the potential fundamental R&D requirements in the area. The focus of the presentation was the reduction of iron ore using renewable (or low-carbon) hydrogen and the scientific issues this could present. During the lecture, Dr Burgess discussed existing steelmaking technologies, the properties of steel and issues presented by a possible renewable route to steel.

BUILDING THE SUPERPOWER OF THE LOW CARBON WORLD ECONOMY

MEI was pleased to partner with the Faculty of Business and Economics to host the webinar Building the Superpower of the Low Carbon World Economy in June 2020. This webinar was the fifth in a series by Professor Ross Garnaut, called the RESET Webinar series. Professor Garnaut's RESET seminars described the pandemic and its economic impact; the challenges that Australia, developed democracies and the international community carried into the pandemic; and discussed alternative paths forward for Australia in the challenging post-pandemic world.

Learn more about this event here.
https://fbe.unimelb.edu.au/alumni/events/public-lectures/ross-garnaut-reset-lecture-series/reset-building-the-low-carbon-superpower

NEGATIVE EMISSION TECHNOLOGIES IN AUSTRALIA: LAUNCH OF NET ZERO REPORT

In August 2020, the Negative Emission Technologies in Australia report was launched in a webinar by MEI and the Peter Cook Centre for Carbon Capture and Storage Research. The launch included selected participants from the NETs Roundtable, a project which brought together 40 invited participants from academia, industry, state and federal government departments, NGOs and research organisations in June 2019. Panellists included Tony Wood, *Energy Program Director, Grattan Institute*, Dr Andrew Lenton, *Principal Research Scientist, CSIRO Climate Science Centre*, Professor Robin Batterham, *Kernot Professor of Engineering, the University of Melbourne*, Dr Nasim Pour, *Strategic Economic Consultant, Jacobs,* and David Byers, *Chief Executive, CO2CRC*. The experts discussed and answered questions about technologies that could be developed in Australia to contribute to negative CO2 emissions.

HYDROGEN FUTURES WORKSHOP

In March 2020, MEI hosted the Hydrogen Futures workshop with the Australian Academy of Technology and Engineering (ATSE) and the National Academy of Engineering of Korea.

The workshop explored the strategies that Australia and Korea are implementing to move towards a hydrogen economy. Attendees discussed a variety of topics including hydrogen policy, research and development, commercial business challenges and government and sectoral approaches. Presenters represented industry, government and academic institutes. The workshop was a successful event and strengthened Australia and Korea's relationship, offering different perspectives on transitioning to a hydrogen economy.

Some attendees of the Hydrogen Futures workshop, including (left to right) Dr Sarah Ryan FTSE, *Board Member, Woodside Energy,* Dr Patrick Hartley, *Leader, CSIRO Hydrogen Industry Mission,* Dr Bruce Godfrey FTSE, *ATSE Vice-President,* Professor Chinho Park, *Yeungnam University,* Dr Fiona Beck, *ANU,* Professor Oh-Kyong Kwon, *NAEK President*, and Professor Michael Brear FTSE, *Director, Melbourne Energy Institute.*

POPULAR ARTICLES

The following articles were authored by MEI researchers and Fellows. The articles appeared in Pursuit, the University of Melbourne's academic research publication, and The Conversation, a news website that publishes stories written by academics and researchers.

Making milk powder less energy intensive

By Dr George Chen, Professor Sandra Kentish, Professor Sally Gras, University of Melbourne

Published on 12 February 2020

A new pilot study demonstrates the potential to use a cheese by-product to concentrate skim milk, reducing the energy required in dairy powder production.

https://pursuit.unimelb.edu.au/articles/making-milk-powder-less-energy-intensive

Wearable devices that use human energy

By Dr Peter Sherrell, Mr Nick Shepelin, Professor Amanda Ellis and Dr Eirini Goudeli, University of Melbourne

Published on 25 February 2020

The human body produces a tremendous amount of energy. Now, researchers are looking at different ways to capture, reuse and recycle this energy to power our electronic devices.

https://pursuit.unimelb.edu.au/articles/wearable-devices-that-use-human-energy

Machine learning to scale up the quantum computer

By Dr Muhammad Usman and Professor Lloyd Hollenberg, University of Melbourne

Published on 16 March 2020

A machine learning framework has been created to precisely locate atom-sized quantum bits in silicon – a crucial step for building a large-scale silicon quantum computer.

https://pursuit.unimelb.edu.au/articles/machine-learning-to-scale-up-the-quantum-computer

Oil wars, petrol prices and COVID-19

By Associate Professor David Byrne, University of Melbourne

Published on 1 April 2020

The COVID-19 pandemic and global oil price wars are having an economic impact worldwide, but one consequence is lower fuel prices at Australian petrol pumps for the foreseeable future.

https://pursuit.unimelb.edu.au/articles/oil-wars-petrol-prices-and-covid-19

Further to fall, harder to rise: Australia must outperform to come out even from COVID-19

By Professor Ross Garnaut, University of Melbourne

Published on 19 May 2020

Australia's economy has prospered due to open borders and international trade. It has much more to lose from disruptions.

https://theconversation.com/further-to-fall-harder-to-rise-australia-must-outperform-to-come-out-even-from-covid-19-138802

Investing in social housing during a pandemic

By Dr Katrina Raynor, Professor Alan Pert, Professor Bec Bentley, Associate Professor Robert Crawford and Dr Ilan Wiesel, University of Melbourne

Published on 10 June 2020

Australia needs a National Housing Strategy, as well as consistent funding and policy mechanisms, to reverse our long-term declines in social housing.

https://pursuit.unimelb.edu.au/articles/investing-in-social-housing-during-a-pandemic

'A wake-up call': why this student is suing the government over the financial risks of climate change

By Professor Jacqueline Peel, University of Melbourne and Rebekkah Markey-Towler, University of Melbourne

Published on 27 July 2020

Climate-related financial risks have already entered the corporate boardroom. With this case, they've now come knocking at the government's door.

https://theconversation.com/a-wake-up-call-why-this-student-is-suing-the-government-over-the-financial-risks-of-climate-change-143359

From grapevine waste to a sustainable building material

By Marcus Wong, Dr Peter Sherrell, Dr Simone Hendrikse and Professor Amanda Ellis, University of Melbourne

Published on 28 September 2020

Grapevine prunings are an abundant source of agricultural crop waste that are now being turned into recycled building materials.

https://pursuit.unimelb.edu.au/articles/from-grapevine-waste-to-a-sustainable-building-material

Sustainable success for Australian business

By Professor Glenn Hoetker, University of Melbourne

Published on 16 October 2020

The disruption of COVID-19 is an unexpected opening for businesses to adopt more sustainable practices – elevating the practice of sustainability across industries.

https://pursuit.unimelb.edu.au/articles/sustainable-success-for-australian-business

3 billion animals were in the bushfires' path. Here's what the royal commission said (and should've said) about them

By Ashleigh Best, University of Melbourne; Professor Christine Parker, University of Melbourne, and Professor Lee Godden, University of Melbourne

Published on 9 November 2020

The royal commission made welcome and necessary recommendations around helping wildlife after hazards. But it's not enough to focus only on response.

https://theconversation.com/3-billion-animals-were-in-the-bushfires-path-heres-what-the-royal-commission-said-and-shouldve-said-about-them-149429

The investor-led push on climate change

By Professor Jacqueline Peel and Rebekkah Markey-Towler, University of Melbourne

Published on 30 November 2020

Investor-led pressure on Australian companies is forcing boards to adopt sustainable business practices to meet climate change goals.

https://pursuit.unimelb.edu.au/articles/the-investor-led-push-on-climate-change

GOVERNMENT SUBMISSIONS

The following submissions have been made by MEI:

DESIGN ISSUES PAPER FOR THE PROPOSED AUSTRALIAN ENERGY TRANSITION RESEARCH PLAN

The University of Melbourne provided a submission on the Design Issues Paper for the proposed Australian Energy Transition Research Plan to the Australian Council of Learned Academies (ACOLA). The submission discussed the scope, recommended processes and products delivered, governance, potential risks, funding and ongoing support of the Research Plan, as well as the University of Melbourne's proposed involvement.

Date of submission: 15 May 2020

Lead Academic: Professor Michael Brear FTSE, FCI, FIEAust, *Director, Melbourne Energy Institute*

In consultation with: Professor Pierluigi Mancarella, *Leader, MEI Energy Systems Program,* Professor Richard Sandberg, *Leader, MEI Power Generation and Transport Program,* Dr Robyn Schofield, *Director, Environmental Sciences and Leader,* Professor Robin Batterham *AO FAA FTSE FREng FNAE FSATW FCAE FINAE FAusIMM FIChemE FISS FAIM FIEAust,* Professor Mark Cassidy *FAA FTSE FIEAust,* Dr Sangeetha Chandra-Shekeran, *Deputy Director, Melbourne Sustainable Society Institute,* Professor Peter Cook *CBE FTSE,* Professor John Freebairn *AO FASSA,* Professor Ross Garnaut *AC FASSA,* Professor Lee Godden *FASSA,* Professor Ralf Haese, Professor Fiona Haines *FASSA,* Professor David Jamieson *FIP FAIP,* Professor Sandra Kentish *FTSE FIChemE FRACI FIEAust,* Professor Paul Mulvaney *FAA,* Professor Mike Sandiford *FAA,* Professor Geoff Stevens *FTSE* and John Wiseman.

VICTORIAN GOVERNMENT INQUIRY INTO NUCLEAR PROHIBITION

At the request of the Environment and Planning Committee of the Legislative Council of Victoria, Professor Michael Brear submitted a response to the inquiry into Nuclear Prohibition in Victoria. In this submission, Professor Brear made a number of recommendations to the inquiry, the most notable being that:

- Australian governments should adopt a binding, technologically agnostic, economy-wide and carbon based GHG abatement policy that has responsible environmental objectives, otherwise the most cost effective and secure decarbonisation pathways will never be realised;
- all existing bans on nuclear power generation should be lifted since it is not clear that we can achieve our environmental and social objectives without it.

Date of submission: 9 September 2020

Lead Academic: Professor Michael Brear, FTSE, FCI, FIEAust, *Director, Melbourne Energy Institute*

COMMUNICATIONS AND MEDIA

MEI has devoted resources and expertise to the production and dissemination of the Institute's research. Contributing to the national energy debate and presenting a range of views on relevant and critical industry issues is one of MEI's key objectives.

NEWSLETTERS

energy@melbourne – Melbourne Energy Institute external newsletter

MEI's monthly external newsletter, energy@melbourne, is our key communication tool. With a subscriber list of over 5000, information about MEI's research as well as important news and events is sent directly to stakeholders in industry, government, community and academia.

Bright Sparks - Melbourne Energy Institute internal newsletter

MEI's monthly internal newsletter, Bright Sparks, communicates news and events to over 1000 subscribers including students, academics and professional staff members. Each month we aim to communicate educational and professional opportunities for our energy researchers, including seminars, events and conference announcements, calls for papers, and employment opportunities through MEI's links with industry, government and other research providers.

MEDIA

Opinion: Hydrogen and CCS could be the energy road-map winners

In an opinion piece published in the Australian Financial Review on 1 June 2020, Professor Peter Cook, *Senior Adviser at the Peter Cook Centre for CCS Research at the University of Melbourne*, and David Byers, *Chief Executive of CO2CRC*, wrote about how hydrogen and CCS could be the energy road map winner.

https://www.afr.com/policy/energy-and-climate/hydrogen-and-ccs-could-be-the-energy-road-map-winners-20200531-p54y1d

Impact of the global pandemic on the coal industry

Professor Michael Brear was interviewed by ABC Gippsland radio on 9 June 2020 to discuss how the COVID-19 pandemic has impacted the coal industry and electricity generation in Australia.

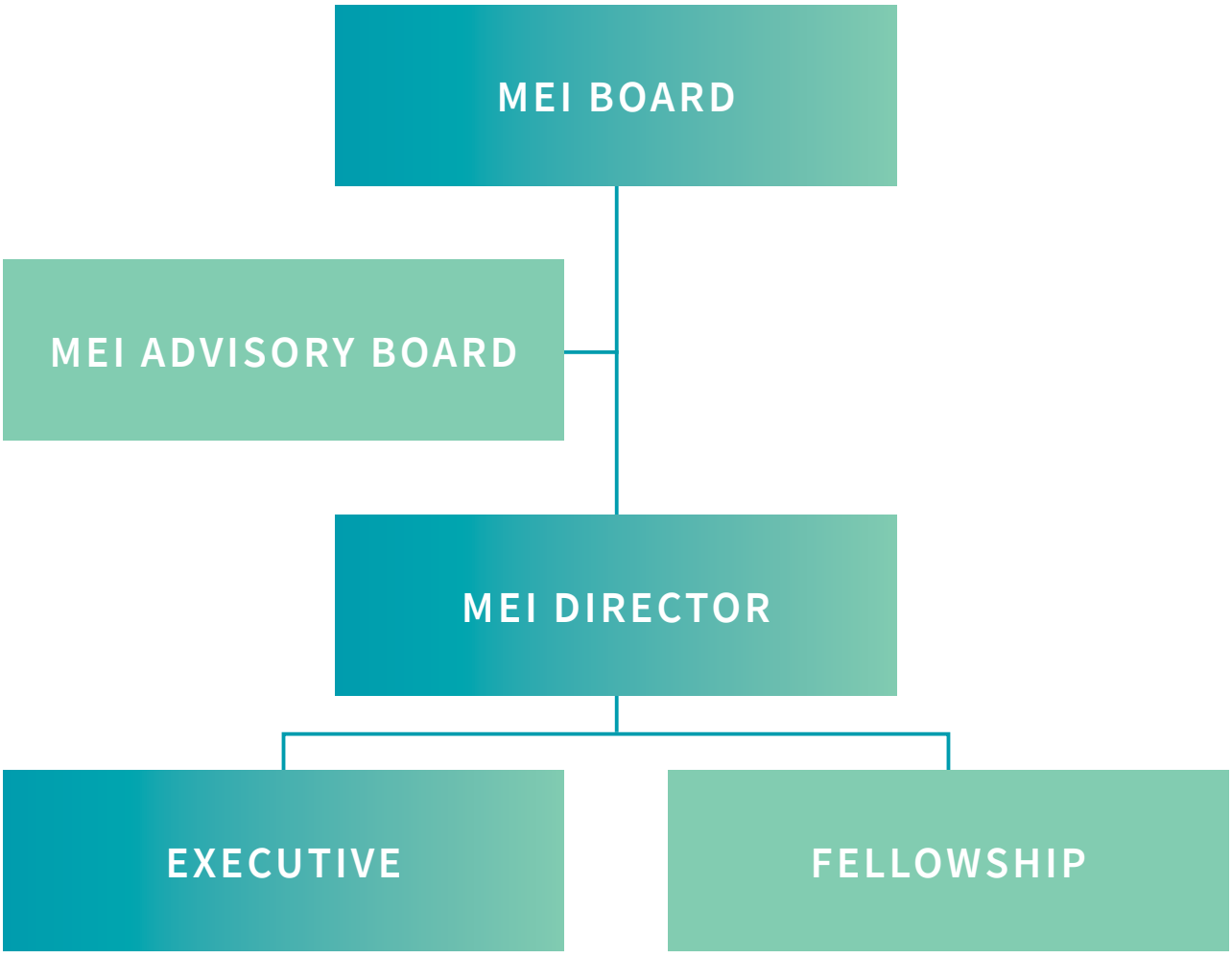
'No integrity': Why states can't be left holding the environment file

Professor Lee Godden, *Law Professor and MEI Fellow*, was interviewed by the Sydney Morning Herald on 25 July 2020, to discuss Australia's environment laws in relation to the dramatic decline in threatened species and their habitats.

https://www.smh.com.au/politics/federal/no-integrity-why-states-can-t-be-left-holding-the-environment-file-20200723-p55eu3.html

GOVERNANCE

The Institute reports to the MEI Board for operational matters. The Institute Staff and the Executive Committee work together to operate MEI, and the Advisory Board and Fellows provide strategic advice. A small team of professional staff support the Director in all Institute activities.



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Ms Anita La Rosa, *Institute Manager, Melbourne Energy Institute*

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Mr Brian Pang, *Senior Business Development Manager, Faculty of Engineering and IT*

Professor Richard Sandberg, *MEI Program Leader Power Generation and Transport, and Chair of Computational Mechanics*

Dr Robyn Schofield, *MEI Program Leader Environment and Resources, Senior Lecturer, and Director of the Environmental Science Hub*

Ms Karen Van Sacker, *Director of Advancement (STEM)*

INSTITUTE FELLOWS

Professor Lu Aye, *Professor, Department of Infrastructure Engineering, Faculty of Engineering and Information Technology*

Professor James Bailey, *Professor, School of Computing and Information Systems, Faculty of Engineering and Information Technology*

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Professor Shyamali Dharmage, *Nhmrc Professorial Fellow, Melbourne School of Population and Global Health, Faculty of Medicine, Dentistry and Health Sciences*

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Professor Ross Garnaut, *Professorial Research Fellow, Department of Economics, Faculty of Business and Economics*

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Dr Eirini Goudeli, *Lecturer, Department of Chemical Engineering, Faculty of Engineering and Information Technology*

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Dr Robyn Schofield, *MEI Program Leader Environment and Resources, Senior Lecturer, and Director of the Environmental Science Hub, School of Earth Sciences, Faculty of Science*

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Professor Doreen Thomas, *Honorary, Department of Mechanical Engineering, Faculty of Engineering and Information Technology*

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Dr Maria Vrakopoulou, *Lecturer in Power Systems Dynamics, Department of Electrical and Electronic Engineering, Faculty of Engineering and Information Technology*

Dr Wallace Wong, *Senior Lecturer, School of Chemistry, Faculty of Science*

Professor Rachel Webster, *Professor, School of Physics, Faculty of Science*

Associate Professor Yi Yang, *Associate Professor, Department of Mechanical Engineering, Faculty of Engineering and Information Technology*

Professor Margaret Young, Professor, *Environmental Law, Melbourne Law School*

FINANCIAL SUMMARY

INTERNAL INCOME	$
Core funding from Deputy Vice-Chancellor (Research)	$950,000
Other income	–
TOTAL INCOME	**$950,000**
EXPENDITURE	
Institute staff salaries	$503,409
Administration and general costs	$10,712
Events and communication	$10,712
Research project support salaries	$204,604
Research project seed funding	$50,000
Research project seed funding commitments	$122,881
Partnership development	$28,596
TOTAL EXPENDITURE	**$930,915**
EXTERNAL INCOME	
ARC	$6,195,000
Industry – direct contract and leveraged	$3,558,222
Government	$4,352,000
Philanthropy	–
TOTAL EXTERNAL INCOME	**$14,105,222**

THE UNIVERSITY OF MELBOURNE

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