POWER AND RENEWABLE ENERGY

Energy capability within the Faculty of Engineering, Computer and Mathematical Sciences

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TODAY’S ENERGY MARKET IS EVOLVING AT A RAPID PACE AND FOCUSED RESEARCH IS CRITICALLY NEEDED TO MODERNIZE THE WAYS WE GENERATE, DISTRIBUTE, AND MANAGE TODAY’S ENERGY—BOTH ON THE ELECTRICITY GRID AND AS WELL AS IN GAS PIPELINES.

Electrification is a pervasive phenomenon that is driving change—this occurs in everything from end-user products, advanced power electronics switching and smart control systems on the grid, to renewable sources of energy with marginal operating costs. These factors have transformed the grid into a dynamic place.

Whilst this presents engineering challenges, it also creates exciting opportunities for Australia. An energy policy vision for Australia is the intentional over-installation of renewables that will not only reduce the need for storage but will create excess electricity at marginal operating cost. This oversupply can then open up opportunities for economic generation of alternative energy vectors such as hydrogen for both local industry and mass export.

This document consolidates the considerable engineering expertise we have in the energy sector for both meeting such vision and also assisting with needed transitional solutions as Australia presses towards its energy future.

Professor Derek Abbott, Convener

FOREWORD

Professor Derek Abbott was with the General Electric Company (GEC), London, UK, from 1978 to 1986 and has since been with University of Adelaide.

His interests are in multidisciplinary applications of electrical and electronic engineering, complex systems, and energy policy.

He is an Honorary Fellow of Engineers Australia, Fellow of the Institute of Physics (IoP), UK, and a Fellow of the IEEE, USA. He has won a number of awards, including the South Australian Tall Poppy Award for Science (2004), the David Dewhurst Medal (2015), the Barry Inglis Medal (2018), and the M. A. Sargent Medal (2019) for eminence in engineering.
The University of Adelaide is an important contributor to the scientific process of identifying solutions to deliver forward thinking technical, economic, social, and environmental outcomes for Australia and on the international stage.

I am delighted to have this opportunity outline South Australia’s role in our nation’s energy future, as it is well-aligned to the University’s expertise.

Our State is committed to deliver affordable, reliable, secure and clean electricity supplies in a transitioning national energy market. Without a doubt, South Australia is leading the clean energy transition—even in a world-wide context.

Given the challenges we have faced, the world is paying close attention to our remarkably fast transition. They are also paying particular attention to how we are responding to and addressing those challenges. Our technological advancements, coupled with our abundant wind and sun, provide us with huge opportunities both locally and globally.
Australia is well on the way to achieving net 100% renewables by the early 2030s. Our renewable assets will not only provide us with affordable clean energy—they will also provide new opportunities trade and economic growth, including in the growing field of renewable hydrogen production.

While there is plenty of upside, some of the changes occurring in South Australia also present significant challenges to SA and to the existing management of the national energy market.

The so-called duck curve in our energy generation is created by the extremely high penetration of rooftop solar in South Australia. This curve represents high levels of solar PV generation leading to low demand from the grid during the day, followed by lower PV generation and a pick-up in consumption during the evening. Keeping pace with the increasing number of solar panel owners connecting to the grid has also created challenges for network operators—both at a transmission and distribution level—in trying to manage customers’ needs.

South Australia is working to address these issues, as well as increasing our connection with the rest of the grid so we can both improve reliability locally and create export opportunities.

In partnership with industry and market bodies, our plan includes:

- Support for a $1.5 billion interconnector to NSW;
- A $50 million Grid Scale Storage Fund;
- The largest planned per capita rollout of home batteries in the world through the $200 million Home Battery Scheme and the Tesla VPP;
- New approaches to managing demand;
- Accelerating gas exploration to improve supply; and
- Seizing the huge opportunities created by the emerging global market for hydrogen.

Firstly, to improve reliability and increase our capacity to export requires improved connection to the National Electricity Market. Project EnergyConnect—otherwise known as the SA-NSW interconnector—is the most advanced project in the Australian Energy Market Operator’s Integrated System Plan. The South Australian Government has underwritten $14 million of early work by ElectraNet and TransGrid to expedite delivery of Project EnergyConnect as soon as possible.

Renewable energy developers are already lining up to take advantage of new renewable energy zones along the interconnector route. If regulatory and development approvals line up, we can expect the first stage of the project to be up and running as early as 2022. Other steps are being progressed to address our supply and demand issues with a mix of storage, demand management, and supply integration initiatives. Our $50 million Grid Scale Storage Fund aims to bring forward investment in new storage technologies capable of addressing the intermittency of our State’s increasing renewable electricity supply.

Neoen’s expansion of its Hornsdale Power Reserve is the first project to be supported from this fund with $15 million awarded for the delivery of additional services to improve network security. With the first 100 MW of 129 MWh of storage capacity, developed by Neoen and Tesla under the previous state government, we will now support the 50% expansion of The Big Battery near Jamestown, which will be another Australian-first.

I expect this expansion to lead to significant savings for consumers by allowing South Australia to integrate even more renewable energy into our energy system. It will also be a world-leading demonstration of how battery storage can provide inertia, protecting the security of the grid by keeping frequency consistent. This is inertia that used to be provided by power stations such as Northern and Playford.

The 50 MW or 65 MWh expansion will enable a much faster response time to system disturbances such as network faults and trips. Within milliseconds, the Hornsdale Power Reserve can stabilise the grid, avoid price volatility in the market and reduce the risks of blackouts. This expansion will also help develop markets for these other services, helping to get more batteries into the system more quickly. The State Government is currently engaged in negotiations with the other shortlisted applicants for the Grid Scale Storage Fund and I look forward to making more announcements about these projects very soon.

Increasing storage at a household level is also being rolled out. South Australian households have already made a significant investment in rooftop solar, with one third of homes now generating their own solar power. The $100 million Home Battery Scheme is an Australian-first, designed to optimise these investments by encouraging the uptake of household storage technologies. This scheme gives all grid-connected South Australians an opportunity to access subsidies of up to $6,000 towards the cost of a home battery that can reduce their power bills, together with $100 million in low-interest loans. As of November 2019, more than 4,600 South Australian homes have had new batteries installed or are awaiting installation.

Another success story is the South Australian Virtual Power Plant. The South Australian Government and retailer Energy Locals both support the Tesla Virtual Power Plant (VPP). The VPP comprises a network of home solar photovoltaic and Tesla Powerwall battery systems across the state working collectively to generate electricity at the same rate as a power station. We have installed more
The Plan for Accelerating Exploration Gas grant program—or PACE Gas—has brought forward investment in the Cooper Basin and supported the renaissance of the onshore Otway Basin.

Together, the new supply brought forward by PACE Gas grants is helping to keep downward pressure on gas prices and provide new competitive sources of supply for local users such as power plant operators. South Australia is also in prime position to be the hydrogen export centre of Australia. In September, Adelaide hosted the 8th International Conference on Hydrogen Safety, the ideal venue to have launched our Hydrogen Action Plan for South Australia.

The Hydrogen Plan sets out a vision for leveraging our wind, sun, land, infrastructure and skills to become a world-class renewable hydrogen supplier of choice. We already have a suite of renewable hydrogen production projects under development in South Australia, including a plan to blend hydrogen into the domestic gas distribution network. The first of these breakthrough hydrogen projects is on track to begin operation next year.

Our focus will be on supporting existing and new renewable hydrogen projects in South Australia to build on the domestic use of renewable hydrogen as a stepping-stone to exports. Hydrogen exports are modelled to provide $4 billion in economic benefits and 7,000 jobs to Australia by 2040. We are determined that South Australia will become a very prominent part of this emerging and very real opportunity.

We will export renewable hydrogen to our trading partners in Asia, who are already looking towards hydrogen consumption as a key part of their own energy transitions—but they cannot make green hydrogen themselves. As part of the action plan, we have committed to a landmark study of existing and potential infrastructure required for an international-scale renewable hydrogen export value chain. The resulting tool and prospectus will provide interested parties with a solid base of information they need to develop hydrogen production and export infrastructure in South Australia.

South Australia is a large state with remote communities, prospective mineral regions, and long transport routes, and so hydrogen is also an exciting flexible fuel for our future domestic use. At the 2019 COAG Energy Council meeting in Perth, Australia’s National Hydrogen Strategy, written by Chief Scientist Dr Alan Finkel, was adopted by all states and the Commonwealth. South Australia will become a producer, consumer and exporter of green hydrogen and green ammonia in the not too distant future.

So what progress is there so far on our main objectives in this area of more affordable, more reliable and cleaner energy? The Essential Services Commission of South Australia recently reported South Australian consumers are already beginning to benefit from some of these energy initiatives. The report showed that average annual residential electricity market offer prices fell by 3% in the 12 months to 30 June 2019. This is equivalent to an average annual bill reduction of $62 for a customer on a market offer. Moreover, the Australian Energy Regulator (AER) confirmed that South Australia’s 2019 electricity costs are lower than they were in 2018.

As a government, we have set an ambitious target of accelerating annual Gross State Product growth to three per cent by focusing on nine key sectors of the economy. There is much more to do. Investment in low cost and affordable energy will be a key factor in generating the jobs, infrastructure, skills and innovation needed to achieve our economic growth objectives. Notwithstanding the fact that significant challenges exist, South Australia’s energy future is bright. Our emergence as a clean energy transition leader on the global stage is creating new opportunities for investment, growth and jobs.

I hope I have provided some insight into our vision, our successes, and the many opportunities we are seeking to grasp as a State as we continue on the path to becoming a world leader in the clean energy transformation. I am delighted that the foregoing document outlines tremendous expertise, vision, and capability that exists at the University of Adelaide, which is in perfect alignment with the State’s strategic direction.

Hon Dan van Holst Pellekaan MP
Minister for Energy and Mining
The focus on environmentally sustainable sources of energy and fuels is driving global energy agendas and underpinning major industrial, technological and infrastructure decision-making around our energy future.

At the national level, we find an interplay between (i) the politics of National Energy Policy, (ii) changes in market dynamics driven by short-term supply demand imbalances, and (iii) shifts in net baseload versus distributed and intermittent electrical energy supply.

Against this backdrop there exists an increase in wind and solar energy utilisation, the use of batteries and pumped hydroelectricity. Moreover, there is an increasing interest and technological progression in future energy and fuel sources such as hydrogen, concentrated solar thermal and biomass. There is an increasing awareness across industry, government and the general public that energy systems require “big picture” analysis and strategic thinking in order to ensure network reliability, affordability, and lower emissions.

Locally, South Australia’s adoption of renewable energy generation and storage technologies over the past decade, has created opportunities to take world-leading initiatives in renewable energy solutions. This has necessarily increased the heterogeneity and complexity of the energy network, which in turn has led to challenges around robustness and network predictability.

While the Government seeks to address the rising cost of electricity and energy generators and distributors look to manage an increasingly complex energy mix, a variety of new companies are looking to South Australia for the manufacture and deployment of greener and more sustainable energy generation and storage solutions (such as Tesla, Sonnen, GFG Alliance).

It is likely within the next few years that South Australia will inflect to a position where the majority of its electrical supply is generated from distributed sources—such as photovoltaic (PV) panels and wind generated power—with attendant risks created by the physical network moving beyond the known parameters of current network modelling.

The Faculty of Engineering, Computer and Mathematical Sciences (ECMS) can position the University of Adelaide as a leader in the transitioning energy landscape.
Over the last decade, South Australia has positioned itself as a global leader in the adoption of renewable electricity through a strong domestic uptake of rooftop and commercial scale photovoltaics, the deployment of wind turbine farms across the state and, more recently, the diversification of utility-scale solar thermal and energy storage projects.

**Energy Vectors Generation and Utilisation**

The move to close the cycles of energy resources requires us to think of means to generate energy vectors such as hydrogen, ammonia, syngas, liquefied natural gas (LNG) and bio-fuels that can store, transfer and release energy in an efficient and cost competitive manner.

Closing the cycle requires future energy vectors to be carbon neutral when generated and utilized. This can potentially be achieved through capturing of emitted carbon from fossil based fuels, either before it is used or capturing the carbon from large industrial systems, sequester it or converted back to fuel.

An alternative approach is the direct utilization of renewable energy sources for all sectors especially when they coincide with the geographical location where they are being generated. This is particularly pertinent for concentrating solar energy, where thermal energy can potentially replace the use of fuels as the source of heat for industrial processes or power generation.

There are major opportunities for Australia to develop technologies and approaches that allow the cost effective generation of energy vectors, such as hydrogen and its derivatives that can be transported and utilized in different parts of the country or as an export commodity in the future.

Australia’s abundance of renewable energy is a major advantage that can only be fully utilized when effective energy vectors are used to transport this energy to markets where they are most needed and that generate the maximum return for the country.

**South Australian Government**

The South Australian Government has shown commitment to the energy sector strategically, socially and economically, as more companies look to work with the State in deploying renewable technologies from the domestic through to utility scale solutions. The Government leads and coordinates a broad range of cross-portfolio renewable energy and energy storage projects. Areas of focus include:

- Large scale renewable energy generation and storage, such as wind, solar PV, bioenergy, battery, pumped hydro, solar thermal and thermal storage;
- Integrated electricity management through a Virtual Power Plant model;
- Behind-the-meter energy production such as rooftop solar, bioenergy, distributed storage, energy efficiency and demand management;
- Hydrogen production, domestic use and for export;
- Uptake of zero carbon emission vehicles and investment in charging and refuelling infrastructure;
- Supply chain development of low carbon technologies; and,
- Research and industry partnerships in low carbon technologies.

Major projects currently underway in South Australia include:
- The Riverland Solar Storage project led by the Lyon Group to build Australia’s largest solar farm in South Australia’s Riverland;
THE ELECTRICAL ENERGY CHALLENGE

The fundamental challenge for power generators and distributors in moving to a greener, more sustainable energy future is ensuring the reliability, affordability and security of electricity to all end users. This sector/industry scale transformation needs to be driven by informed decisions that optimise resources and infrastructure, utilise the most effective and efficient technologies and minimise disruption and uncertainty.

Recent reviews of the national electricity market have determined that Australia needs to increase system security and ensure future reliability in this market. The security and reliability of the national electricity grid has been compromised by poorly integrated variable renewable electricity generators coinciding with the withdrawal of older coal and gas-fired generators.

Though seemingly immense, this challenge gives rise to a multitude of opportunities including energy storage and utilisation; advanced energy conversion technologies; a move from centralised to decentralised scenarios; use of smart and micro grids; peer to peer energy trading; future fuels and biomimetic approaches and new materials for energy generation, conversion and storage.

• Comprising a new 330 MW solar generation plant (two phases) and 100 MW battery storage system (Development Application approved, planned construction Q1 2019);
• The Port Augusta Renewable Energy Park led by DP Energy will be one of the largest hybrid renewable energy projects in the southern hemisphere, consisting of 59 wind turbines and almost 400 hectares of solar photovoltaic (PV) panels amounting to a combined generation capacity of 375 MW (Development Application approved, Approaching financial close); and
• SA Water $300 million investment in the installation of 154 MW of solar PV and 34 MWhs of energy storage across more than 70 of the utility’s sites. Adelaide-based Enerven, a wholly-owned subsidiary of SA Power Networks, will deliver the project.

The South Australian Government is also incentivising the energy storage market by offering funding schemes that support investment in both domestic and utility-scale storage systems.

The Home Battery Scheme (HBS) is a $100 million State Government investment that will subsidise up to 40,000 domestic energy storage systems with the aim of alleviating rising energy prices and providing increased stability and security for the local energy market.

Through the HBS, households are able to choose whether or not their home battery system is part of a broader virtual power plant to help address electricity network instability issues and balance out peak power demands.

At the utility-scale, the South Australian Government launched the $50 million Grid Scale Storage Fund (GSSF) on 19 November 2018, aiming to accelerate the roll-out of grid-scale energy storage infrastructure across the state.

Tesla and the South Australian Government have partnered to establish the SA Virtual Power Plant (SA VPP), a network of up to 50,000 homes across South Australia to form the world’s largest virtual power plant.

The first phase of the project is now complete with 100 home energy systems installed around the State. Phase Two, currently underway, will trial the systems working as a virtual power plant and their ability to generate the additional energy for an extra 320 Housing Trust households.

Petroleum Resources

Realising the full potential of the local non-renewable sector, such as gas reserves from the Cooper/Eromanga Basin in the northeast and the Otway Basin in the southeast, is also a critical component of South Australia’s energy future. The identification, management and optimised recovery of non-renewable resources are key factors in the State’s economic prosperity and in Australia’s energy security and in our global competitiveness.

Fundamental and applied knowledge in conventional and unconventional energy resources, reservoir characterisation and production optimisation will be critical in generating a solution to secure efficient, reliable and affordable power.

National Energy Resources Australia (NERA), one of the Federal Government’s six Industry Growth Centres, was established to maximise the value of the energy resources industry to the Australian economy. Challenges include predicting market volatility, addressing high capital and operational expenditures of exploration and production and emissions management.

NERA has identified opportunities for the energy sector that require a combination of business development, adoption of new technologies and industry-focused research. These include:

• Increasing collaboration amongst operators to maximise asset productivity;
• Improving collaboration between operators and technology and engineering service providers to increase innovation and productivity;
• Leveraging the critical mass emerging in Australian operations to develop an export-oriented and competitive service and technology sector; and,
• Developing shale and tight gas basins to support domestic demand, and potentially for export.

The Australian School of Petroleum and Energy Resources and Energy Resources within the faculty houses a wide ranging capability and expertise that services both current and future petroleum-related research. A capability summary of the petroleum research domain is provided in Appendix 2.
In recent years, interest in hydrogen has risen dramatically as nations, corporations and research organisations acknowledge hydrogen as a critical component in the decarbonisation of power generation, transport, and thermal energy. Hydrogen can be utilised in a range of ways including:

- Fuel Cell Electric Vehicles (FCEVs) such as buses, trucks, agricultural equipment and cars;
- Electricity Grid Firming such as grid connected electrolysers that can be ramped up and down to help manage grid stability and produce hydrogen for energy storage;
- Remote Area Power Systems (RAPS) utilising hydrogen produced via dedicated renewable energy inputs,
- Industrial Feedstock including the incorporation of clean hydrogen in industrial processes (replacing hydrogen derived from hydrocarbons); and,
- As a source of industrial heat to replace fossil fuels to produce materials such as steel.

The CSIRO recently published the National Hydrogen Roadmap that outlines the pathways to creating an economically sustainable hydrogen industry in Australia. The roadmap outlines key elements of the hydrogen value chain that, if appropriately supported through commercial, social, regulatory and R&D initiatives, may have a significant impact in the decarbonisation of the energy and industrial sectors. Most recently, the Council of Australian Governments (COAG) Energy Council has released the National Hydrogen Discussion Paper for consultation (March 2019).

The South Australian Government has also examined the economic viability of the hydrogen economy from a state perspective through its own Roadmap, identifying a number of advantages such as established renewable sector and abundant solar resources, market proximity and transport infrastructure. Currently, South Australia has four key hydrogen projects in various stages of development:

- Hydrogen Super Hub. Located at Crystal Brook, Neoen Australia’s 50 megawatt (MW) Hydrogen Super hub is planned to be the world’s largest co-located wind, solar, battery and hydrogen facility.
- Hydrogen Park SA. Australian Gas Infrastructure Group’s (AGIG) Hydrogen Park located at Tonsley will deliver a 1.25 MW electrolyser plant that will produce hydrogen from renewable electricity. This hydrogen which then be injected into the local gas distribution network.
- The Hydrogen Utility™ (H2U) is set to construct a hydrogen and green ammonia production facility near Port Lincoln, consisting of a 30 MW water electrolysis plant, as well as a facility for sustainable ammonia production.
- The University of South Australia’s demonstration project includes hydrogen production, a hydrogen fuel cell, a flow battery, chilled water storage, and ground and roof-mounted solar photovoltaic (PV) cells. The project will cut campus emissions by 35 per cent and reduce peak demand on the grid.

**THE HYDROGEN ECONOMY**

Hydrogen gas has long been recognised as a versatile energy carrier vector that can revolutionise the energy industry.
The University of Adelaide has invested in intellectual capital displaying the motivation, networks and capabilities (direct and translational) to collaboratively address the challenges faced by the energy sector.

Within the Faculty of Engineering, Computer and Mathematical Sciences (ECMS), energy capabilities can be grouped into seven primary domains:

- Electrical Power Engineering;
- Energy Supply;
- Energy Vectors Generation and Utilisation;
- Energy Storage Solutions;
- Modelling, Optimisation and Machine Learning for Energy Systems;
- Sustainable Systems Design; and,
- Energy Cybersecurity and Platforms.

These primary energy capability domains can be directly mapped to the challenges faced by the local and national energy markets and have great impact in areas of energy generation, distribution and storage; decarbonisation of industrial processes; and the optimisation and security of national markets and infrastructure.

More specifically, ECMS has the opportunity to fill critical gaps in the current energy landscape through the delivery of long term solutions that address challenges such as:

- Grid Reliability: Stability, Resilience and Security; System Monitoring and Control;
- Grid Planning Tools: Storage Planning; Storage Control; Infrastructure;
- Energy Storage: Planning and Management (including capacity and location); Materials Innovation; Storage Optimisation; Pumped Hydroelectricity; Water Systems Modelling; Water Pumping;
- Market Modelling: Market Analysis; Scenario Modelling; Predictive/Responsive Systems;
- Demand Management: Climate and Weather; Market Modelling;
- Infrastructure Management: Optimisation, Risk/Hazard Mitigation;
- Petroleum Exploration and Production: Well Productivity and Enhanced Recovery; Porous Media; Petroleum Geoscience; Carbon Sequestration;
- Industry Transformation: Renewable Energy Generation; decarbonisation of Industrial Processes; Techno-Economic Evaluation; Industrial Transformation; Energy Efficiency;
- Industrial Process Heat: (Solar) Hybrid Technologies; Gasification Technologies;
- Power-to-X: Power-2-Chemicals; Power-2-Fuels; Power-2-Food; Power-2-People;
- Future Fuels: Renewable Fuels (including Hydrogen and its derivatives); and,

In addressing these challenges, the Faculty of Engineering, Computer and Mathematical Sciences has the opportunity to consolidate and grow itself as an international leader in energy transformation and to become a vital contributor to the State’s energy reliability and security.
PRIMARY DOMAINS

1. Electrical Power Engineering
2. Energy Supply
3. Energy Vectors Generation and Utilisation
4. Energy Storage Solutions
5. Modelling, Optimisation and Machine Learning for Energy Systems
6. Sustainable Energy Systems Design
7. Energy Cybersecurity and Platforms
Electricity is being generated, distributed, stored and traded on a range of scales, from individual households, community level, industrial plants and grid scale. This complexity is highlighted by a range of challenges including maximising the use of renewable energy sources while ensuring stability and security of the power system and seeking to minimise overall costs. The future electricity network requires electricity generation, distribution and storage infrastructure to be connected and responsive, possessing the ability to rapidly interpret a wide range of data and respond to issues accordingly. The next generation of management software modelling and optimisation tools can utilise (i) machine learning and artificial intelligence to develop predictive models and demand scenarios, and (ii) rapidly identify failures and deliver responses to minimise customer disruption and protect network infrastructure. These tools will also maximise the benefits of sharing electricity between all customers and at all scales, creating a more resilient electricity network.

Collaborations and Successes
The Power Systems Dynamics Group (PSDG) within the School of Electrical and Electronic Engineering has been working in partnership with the industry for over two decades, undertaking technically challenging projects to help ensure power system security and reliability. Research and development contracts have supported the operations of companies and organisations such as the Australian Energy Market Operator (AEMO), Powerlink Queensland, TransGrid, VENCorp, Transend Networks, Hydro Tasmania and ElectraNet. Their commercial power system software MUDPACK (MUltimachine Dynamics PACKage) is a comprehensive set of interactive tools used to analyse system dynamics and control system design. This software is currently used by all eastern state Transmission Network Service Providers (TNSPs) and AEMO as well as a range of Australian and overseas consulting companies.
The PSDG has also led the development of sophisticated software tools for ElectraNet SA for the purpose of calculating power transfer limits within and between regions of a power system under any set of operating conditions. These planning tools are used by ElectraNet on a daily basis to determine the secure operational limits of the system.

In 2017, the University of Adelaide initiated a strategic partnership with Silanna Semiconductor P/L to establish the Silanna picoFAB, a multimillion dollar research facility for growing advanced, wide band gap semiconductor (WBS) materials.

Silanna’s commercial focus is in the area of silicon carbide (SiC) and gallium nitride (GaN) wide bandgap semiconductor devices. Currently, both SiC and GaN devices are disruptive technologies for power electronics on today’s grid and transformation towards electrification, providing efficient power switches and inverters.

In a further joint initiative between DST, Silanna and the University of Adelaide (IPAS, ECMS, Department of Physics), a new microFAB facility is being established that will have the capability of growing gallium arsenide (GaAs) materials with applications for high efficiency triple junction solar cells and power converters in the lower power range. These new materials are game changers in the area of power electronics, both with the potential for transforming the characteristics of the grid and as an enabling technology for integration of renewables.

**Context Now**

The South Australian Government is actively supporting renewable energy projects within the State that will have significant impact on the way electricity is generated, distributed, stored and traded. These projects range from localised and community-level projects such as the South Australian Virtual Power Plant (VPP) to grid-scale projects such as the Hornsdale Wind Farm and Power Reserve. This drive to increase renewable energy power generation and energy storage coincides with the proposed mothballing of the Torrens Island A Power Station (by 2021) and the deployment of diesel back-up generators at Lonsdale and Elizabeth to manage peak summer demand.

Within this changing landscape, the modelling of short-term dynamics of large grids with high levels of intermittent and variable (asynchronous) generation are not well understood. The data and management tools currently being utilised were designed to cater for a power system with significant base-load (synchronous) capability.

Both Government and electricity providers (generators and distributors) are looking for the most effective way to predict electricity usage, manage peak demands and optimise energy storage to ensure a stable supply. The recent examples of the Hornsdale Power Reserve in responding to fluctuations in the energy grid offer insights into how new technologies can be effectively integrated into the network to ensure stable power delivery.

As indicated earlier, Tesla and the South Australian Government have partnered to establish the SA Virtual Power Plant (SA VPP), a network of up to 50,000 homes across South Australia to form the world’s largest virtual power plant.
In 2016–17, transport, manufacturing and mining represented 65% of total energy consumption in Australia (27.5%, 27.5% and 10.0%, respectively) in contrast to a combined residential and commercial usage of 13.1%.

New technologies are needed to decarbonise the energy-intensive processes, such as those used in the manufacture of iron/steel and cement, since current processes rely almost exclusively on fossil fuels. However, new markets for those few metals for which green processes are available, such as aluminium, are driving investment to develop other green metals. For this reason, the University of Adelaide is directing much of its research effort to supporting the transformation of these ‘difficult to abate’ industries, for which the dominant energy requirement is typically high temperature heat, rather than electricity.

The transportation sector is also in transition. The emergence of electric vehicles is continuing to grow for domestic and light-duty commercial vehicles, while hydrogen is expected to play a growing role for heavier vehicles and long-haul transport owing to its greater energy density.

Technologies such as the use of concentrated solar thermal energy for process heat, thermal storage, and the production of green hydrogen are fundamental to the future of low and zero carbon metals.

New power generating technologies, such as ocean power, also have the opportunity to continue to the lower cost of secure, affordable and sustainable electricity.

Collaborations and Successes

The Centre for Energy Technologies is working closely with a range of research and industry partners, Alcoa, Hatch, ITP, CSIRO and UNSW) on the incorporation of concentrated solar thermal technologies (CST) into the commercial Bayer alumina process. This $15.1 million project is on track to meet its investment targets to justify installation or upscaling of three technology platforms to supply half of the energy requirements for the process with CST.

Researchers are also partnering with the German Aerospace (DLR) and CSIRO to develop a novel technology for co-producing hydrogen, oxygen and sulphuric acid for application in the heavy industrial sector. The value of this technology is particularly high in high temperature industries that require all three of these chemicals. The program is co-developing patented technologies from the partners, while also better understanding their value proposition.

The inaugural High Temperature Mineral Processing (HiTeMP) Forum held in September 2018 and saw members of industry, research and government agencies convene to discuss the drivers, barriers, enablers and opportunities in moving towards the production of zero carbon products from mineral resources.

The forum sought to identify pathways to transform the energy-intensive high temperature processes (particularly targeting the iron/steel, alumina and cement/lime industries) and to better understand how such a transformation might play out. The Second HiTeMP forum, which is scheduled for March 2020, will build on these outcomes to also include copper production.

While significant effort is being directed to incorporate renewable energy into the national electricity market, there is also a need to decarbonise transportation and energy-intensive industrial processes.
In 2019, a $2M Joint Research Centre that seeks to combine wave ad wind energy was announced. The Centre, funded by the Australia-China Science Research Fund sees the University of Adelaide working in partnership with three other Australian universities, CSIRO, industry partner Carnegie Clean Energy, and Chinese partners led by Shanghai Jiao Tong University.

The centre aims to combine wave energy with wind energy, thereby optimising the levelized cost of energy (LCOE) for both technologies. It will do this by looking to share common grid connection, power converters, moorings and even using the turbine towers as wave energy converters. In addition to this funding success, the group’s academic outputs have also been recently recognised.

University of Adelaide contributors include the Acoustics Vibration and Control research group and Optimisation and Logistics group.

**Context Now**

A diverse range of commercial, societal and environmental drivers are emerging to fundamentally transform our energy sources for the new low-carbon economy. These drivers are already emerging in the mining sector, which is increasingly incorporating more renewable energy, and technologies are now also under development for the high temperature industrial processes. While somewhat behind the electricity sector, the transformation of this sector is expected to ramp up now that major corporations, such as BHP, have committed to carbon-zero targets.

Global and national companies in SA, and elsewhere in Australia, are increasingly incorporating low-carbon technologies into current operations both in response to investor demand and to access new markets that emerging for low-carbon products.

The new technologies, including those under development by the CET, have the potential to make significant environmental and economic impact for companies as well as help foster their social licence to operate with communities, councils and government.

The HiTEMP Forum identified hydrogen and concentrated solar thermal energy as being particularly prospective technology platforms to support the transformation of the high temperature process, while increased electrification will continue to become more important, particularly for the low temperature processes.

Partnerships between industry, research and government are vital to enable this transformation be undertaken most cost effectively.
A greener and more sustainable energy future relies not only on the adoption of renewable energy sources for electricity generation and storing electricity for later consumption, but also on the development of new energy sources to fuel industry and society.

Domain Lead
Professor Bassam Dally

Domain Experts
Professor Shizhang Qiao; Professor Graham Nathan; Professor Peter Ashman; Professor Volker Hessel; Assoc. Prof Paul Medwell; Dr Mehdi Jafarian; Dr Alireza Salmachi; Dr Neil Smith
Energy vectors, such as hydrogen, syngas, liquefied natural gas (LNG) and bio-fuels carry energy that can be used to generate electricity, drive engines and produce heat. These fuels can be produced through a number of processes that range in efficiency, energy consumption and amount of carbon emitted during the process. New methods are being developed to help reduce the amount of carbon needed to create these new fuels and advanced materials such as catalysts are being developed to maximise the efficiency of fuel production as well as remove the need for energy-intensive reactions and processes.

Looking at hydrogen, it can be produced through a number of processes and when it is used as a fuel, it produces only water vapour. Hydrogen has a variety of uses including:

- Fuel Cell Electric Vehicles (FCEVs) such as bus fleets, trucks, agricultural equipment and personal vehicles;
- Electricity Grid Firming such as grid connected electrolyzers that can be ramped up and down to help manage grid stability and produce hydrogen for energy storage;
- Remote Area Power Systems (RAPS) utilising hydrogen produced via dedicated renewable energy inputs;
- Industrial Feedstock including the incorporation of green hydrogen in industrial processes (replacing hydrogen derived from hydrocarbons); and,

- A source of thermal energy to replace fossil based heat generators, such as in the production of steel and aluminium.

Fuels can also be derived from waste organic material through a range of processes including torrefaction where the biomass is converted to a higher energy coal-like material and Solar Gasification where biomass is treated with steam to form Syngas using solar energy sources.

Bio-crude oil can also be produced from the bio-solids found in wastewater treatment and waste biomass. Hydrothermal Liquefaction (HTL) is one of the leading methods used to convert this material into valuable products such as transport fuels and their precursors.

The use of thermal energy is also a critical vector when examining industries that require high temperatures, such as mineral processing, oil refining and metal processing. In this case, the storage of thermal energy can help increase the renewable energy share and which can be utilized for power generation, process heat, and renewable fuels generation.

An essential step in the success of this approach is the development of novel thermal storage technologies, spanning sensible, latent and chemical energy. This work is being supported by projects including the Australian Solar Thermal Research Institute and the ARENA Bayer project.

Collaborations and Successes

Muradel Pty Ltd, developers of Australia’s first integrated demonstration hydrothermal liquefaction plant, was founded in December 2010 through a partnership between the University of Adelaide, Murdoch University and SQC Pty Ltd.

The plant is designed to investigate the use of microalgae to treat waste water, ready for reuse or environmental discharge. The remaining biosolids are used to develop and commercialise bio-products such as agricultural soil ameliorants, fish feed and bio-crude oil.

The Future Fuels CRC, which was established in 2018, is an industry focussed RD&D partnership supporting Australia’s transition to a low carbon energy future. The seven year, $81 million program involves over 60 companies, six universities, the energy market operator and two regulators to create a hydrogen economy from a state perspective, identifying a number of advantages such as established renewable sector and abundant solar resources, market proximity and transport infrastructure.

Most recently, the COAG Energy Council has released the National Hydrogen Discussion for consultation Paper (March 2019) and the Australian Chief Scientist is working on a comprehensive national hydrogen strategy that will be released before the end of 2019.

When considering non-renewable fuel sources, the demand for LNG for local baseload power generation (and industrial processes) and its importance to Australian exports is also critical in transitioning to a greener and more sustainable energy future. The need to maximise current wellfield productivity and deliver LNG to the market efficiently and reliably will be important in reducing the cost of LNG and strengthening Australia’s energy future.

The use of concentrated solar heat as an energy source is also being actively investigated by energy-intensive industries. The use of these technologies to drive energy-intensive processes such as refining, reduces and/or bypasses the demand for electricity and grid connection. This technology can be coupled with thermal storage solutions to optimise processes and reduce costs.

Context Now

The movement to develop carbon neutral fuels is a global pursuit. In particular, investigations into the use of hydrogen and ammonia alternative energy vectors, has significant momentum as it is seen as a significant export opportunity to countries such as Japan and South Korea if Australia can strategically develop capabilities in producing, transporting, storing and using hydrogen.

CSIRO has published the National Hydrogen Roadmap outlining the pathways to creating a hydrogen industry in Australia. It defines the key elements of the hydrogen value chain that, if appropriately supported through commercial, social, regulatory and R&D initiatives, will have a significant impact in the decarbonisation of the energy and industrial sectors.

The report also highlighted the need for a reduction in hydrogen production cost through technology development and alternative routes that allows the capture, storage or utilization of the carbon. At least three different technologies are being considered by researchers at the University of Adelaide, which show premise and competitive edge over existing technology.

The South Australian government has also examined the economic viability of the hydrogen economy from a state perspective, identifying a number of advantages such as competitive position, the nexus of renewable sector and abundant solar resources, market proximity and transport infrastructure.

It defines the key elements of the hydrogen value chain that, if appropriately supported through commercial, social, regulatory and R&D initiatives, will have a significant impact in the decarbonisation of the energy and industrial sectors.
Energy storage technologies, together with the analysis and control systems needed to optimise them, are among the technologies needed to manage this variability.

At the household level, the availability of energy storage solutions such as a home battery system integrated with roof top solar, has been on the rise over the past five years. These systems have been designed to deliver added behind the meter energy security for households and businesses looking to protect themselves from power fluctuations and outages. It is also giving customers additional energy flexibility, allowing them to decide when the battery charges and discharges and how it interacts with the electricity grid.

At the regional and grid scale, recent large battery projects such as the Hornsdale Power Reserve have highlighted the role that grid-scale storage can play in responding to fluctuations in the energy grid and offer insights into how new infrastructure and management systems can be integrated into the national electricity. The use of pumped hydroelectric power is also being examined within the State’s water network. Photovoltaic and battery systems are being deployed in catchment areas to aid in the pumping of water upstream. This water can then be released through hydropower plants at times of peak demand. In addition, on a national level, the proposed Snowy 2.0 pumped hydroelectric project and three projects in Tasmania will add to the reliability of the grid. Thermal energy is also well suited to the storage of gigajoules of energy cost effectively through a range of media including molten salts.

Other technologies include compressed air and flywheels, all of which have their complementary niche.

At the international scale, hydrogen is being considered for transporting stored renewable energy from nation-states with large renewable energy resources, such as Australia, to those with more limited resources, such as Japan. There exist a range of alternative hydrogen transport methods, spanning liquefied hydrogen to its conversion to other chemicals including ammonia, or via other routes such as metal halides. These need further development.

The use of energy storage systems presents an opportunity to add an extra level of stability both to the national electricity grid and to the gas pipelines of the future, which are being considered be transformed to transport hydrogen. Through the deployment of such energy storage systems and their associated control systems, the market has the capability to respond more quickly to peak load conditions and minimise supply disruptions.

Collaborations and Successes

In this section we showcase key project successes within the Faculty of Engineering, Computer and Mathematical Sciences exemplifying our energy storage research. It also highlights the groups and expertise that will help develop and assess storage technologies at all scales as well as provide the training required to service future industry.
The Australian Energy Storage Knowledge Bank (AESKB) is a mobile test facility designed for connection to new electrical energy storage technologies. The facility is designed to collect and communicate real-time performance operation and data of the electrical network or device it is connected to.

The AESKB is a resource for the training of a future workforce specialised in microgrid operation, battery storage solutions and the associated health and safety procedures.

The University of Adelaide-led AESKB proposal was successfully funded by ARENA, capturing $1.4 million of funding to build the facility. In addition, SA Power Networks, Energy Networks Association and the South Australian Government have collectively contributed $650,000 towards the project. Currently, the mobile unit is currently deployed on the power network in Cape Jervis, South Australia monitoring both the steady-state and dynamic system performance of the battery through all seasons.

The use of energy storage – at residential, commercial, industrial and utility level – is growing exponentially. This storage includes a range of battery storage technologies and techniques such as pumped hydroelectric and thermal energy storage.

The storage of intermittent renewable energy is also needed for systems that bypass the electrical grid can also be stored, notably for process heat and fuels production.

**Domain Lead**

Professor Angus Simpson

**Domain Experts**

Professor Shizhang Qiao; Professor Shaobin Wang; Professor Gus Nathan; Professor Dusan Losic; Professor Peter Ashman; Professor Bassam Dally; Professor Martin Lambert; Assoc. Professor Nesimi Ertegun; Assoc. Professor Maziar Arjomandi; Dr Yan Jiao; Dr Yao Zheng; Dr Mehdi Jafarian; Dr Woei Saw; Dr Phil van Eyk; Dr Zhao Tian; Dr Mohsen Sarafraz

In the fields of hydroelectric power and storage, The Intelligent Water Decisions Research Group has significant expertise and experience with the detailed simulation and optimisation of the planning, design and operation of energy-related water distribution systems. This includes experience in the planning, design and operation of infrastructure systems that support hydroelectricity and pumped hydroelectricity operations (including infrastructure location, pumping schedules and rates, life-cycle planning and connections to the grid).

Currently the University of Adelaide is collaborating with the University of Melbourne to develop mathematical optimisation tools for SA Water to optimise the buying and selling of electrical energy from and to the AEMO one-half hour spot market to minimise pumping costs and maximise hydropower generation benefits.

The Centre for Energy Technology is leading a $15 million ARENA-funded program to develop technologies using concentrated solar thermal energy system with strong potential to displace 50% of the energy presently supplied with natural gas. The integration of thermal energy storage is an essential element of achieving a high penetration of renewable energy into the system. This project is assessing a range of thermal energy storage systems, spanning commercially-available molten-salt systems through to storage of hot particle and storage of heat in bricks, which can be used to heat air. This project is on-track to exceed the targets and is now also assessing technologies with potential to achieve 100% renewable energy.

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The Centre for Energy Technology is also leading a wide range of programs in the storage of renewable energy in chemicals, such as hydrogen, methanol, ammonia and metals. Chemical energy storage can be highly desirable because its energy density can be one or two orders of magnitude greater than is possible with batteries, which reduces cost. Chemicals can also be traded as a commodity, to be used as a fuel, as an end product or as a feedstock into other industrial processes such as the production of plastics.

The Centre is leading several projects within the Future Fuels CRC to produce hydrogen from solar energy via thermo-chemical routes and to evaluate the benefits of storing hydrogen in pipelines. Within the Australian Solar Thermal Energy Research Institute, the Centre is evaluating how chemical energy storage can be used within a solar thermal power plant to generate electricity.

**Context Now**

Future energy systems are becoming increasingly coupled. Hydrogen can be produced from electricity and converted back again or can be produced independently from electrical networks from solar thermal routes. Some elements of the transportation systems will become increasingly electrified, reducing fuel usage, while others may be converted to operate on hydrogen owing to its greater energy density. Liquid fuels will also continue to be required, particularly for air transportation, to become another form of bottled renewable energy, which can also be produced via electricity or from biomass and/or concentrated solar thermal energy.

As the electricity generation facilities move from predominantly climate-independent coal and gas fired based generation to climate dependent intermittent generation sources of wind, solar and hydropower, a combination of energy storage methods and interconnectors (batteries, pumped hydroelectricity, solar thermal and cross-country electricity grid network interconnection power lines) will be essential to ensure a reliable, lowest cost and sustainable electricity supply to the residential, commercial, industrial and mining sectors.

A similar transformation is occurring more quietly of our gas networks. Our distribution systems are already being transformed to be compatible with hydrogen. A key element of the work of the Future Fuels CRC is to evaluate the most economic pathways for this transformation to occur and also to de-risk the conversion of systems from natural gas to hydrogen or its various blends, by assessing the impact of such a transformation on the wide range of appliances spanning domestic to commercial and industrial.

In addressing the broader energy value chain and in an effort to help address the intermittency of South Australia’s electricity supplies, the South Australian Government is incentivising both the domestic and utility market place by offering opportunities for home owners with solar systems and companies looking to address utility-scale energy storage solutions.

The Home Battery Scheme (HBS) is a $100 million State Government investment that will subsidise up to 40,000 domestic energy storage systems with the aim of alleviating rising power prices and providing increased stability and security for the local energy market and balance out peak power demands.

At the grid scale, the South Australian Government launched the $50 million Grid Scale Storage Fund (GSSF) on 19 November 2018. The GSSF is technology neutral. Pumped hydro energy storage, hydrogen and natural gas storage, solar thermal and battery storage are some examples of applicable technologies. There are two categories of projects eligible for Grid Scale Storage Fund grants.

- **Distributed storage (Stream 1)** - targeting behind-the-meter projects in commercial and industrial facilities (including mining operations) or in the distribution network, which will commence full commercial operations within two years of receiving support from the Fund; and,
- **Centralised (bulk) storage (Stream 2)** - targeting projects located upstream in the electricity network that will commence full commercial operations within four years of receiving support from the Fund.

Similar approaches are also being developed for the transformation of our gas networks. The State Government is supporting a range of hydrogen production demonstration projects to provide storage in hydrogen of the
already-high penetration of renewable energy into our electrical networks. These include:

- Grid-scale storage of energy in a green hydrogen production facility in Port Lincoln with support from the State government, to provide a range of high value products, including adding a variable load to the grid to strengthen it during periods of low demand, the production of high value ammonia as a product and the supply of electricity back to the grid during periods of high demand. In the future such systems may also provide hydrogen to industrial processes;

- A 50 MW hydrogen production facility is also being developed at Crystal Brook by Neoen with support from the SA government to store electricity from a wind farm during periods of high wind availability and low demand in the grid. This will demonstrate the type of solutions that are needed to avoid the curtailment of renewable electricity and increase stability of the network;

- A 2 MW hydrogen production facility is being installed in Tonsley Innovation District to demonstrate the use of hydrogen in domestic applications. Plans are underway to demonstrate the use of hydrogen for mobility and for use in domestic appliances spanning domestic heating through to barbeques.

The State Government has also signed a Memorandum of Understanding with ARENA to help identify and fast track projects that may be eligible for joint funding under ARENA’s Advancing Renewables Program (ARP).

This MoU further underscores the Government’s commitment to the industry, ensuring companies moving into the State have every opportunity to leverage further funding for their project.
Mathematical modelling is all about building abstract representations of real-world systems in order to better understand them, and often with a view to optimising their design and operation.

Working in tandem, machine learning comprises a broad suite of statistical and computing techniques that can extract hidden or complex patterns in large data sets. Once identified, patterns can be exploited for prediction and decision-making.

Suppose we want to build and pro-actively manage a new pumped hydroelectric facility; mathematics, statistics and data analytics have a key role to play at every stage, from hydraulic modelling and optimisation of pumping operations through to optimal scheduling for connectivity to electricity markets, accounting for dynamic price conditions, peak/off-peak tariffs, weather patterns and customer behaviour.

Data analytics and machine learning have a special role to play, because as new energy technologies and systems are operationalised, they begin capturing critical data and information relating to their operations, performance and interactions. There will be a wealth of information contained in this data. Modelling, optimisation and machine learning hold the key to unlocking benefits at every step of the value chain, from power generation to end consumers.

Collaborations and Successes
The Teletraffic Research Centre (TRC) have worked with SA Power Networks (SAPN) since 2014, developing a data analytics platform for analysis, visualisation and optimisation of supply restoration workload and resourcing. The project originated with SAPN’s need to improve visibility and understanding of historical trends and patterns. The project evolved to include event-based simulation modelling of workforce in response to significant events such as storms and heatwaves.

Most-recently, TRC have deployed real-time machine learning algorithms for workload
prediction based on state-wide weather observations, forecasts and other network data. The TRC has worked with clients across a range of industries including defence, telecommunications and utilities. The TRC specialises in end-to-end commercial application of mathematics and statistics for industry, from model development through to end-user web application deployment.

Civil Engineering from the University of Adelaide and the University of Melbourne are working with SA Water Corporation on a joint research project focused on the simulation and optimisation of pumping and hydroelectric energy generation and their work integration with the trading of electricity on the AEMO one-half hour spot price market.

Pumping costs constitute a significant proportion of the operation of SA Water’s water distribution networks (WDNs), and are projected to increase in the future. This partnership has resulted in the development of an extended period hydraulic simulation model of the complex water resources for the MAPL transfers from the River Murray to Adelaide.

In addition, mathematical optimisation techniques are being employed to address issues such as the pump scheduling optimisation problem (PSOP) and the hydroelectricity scheduling optimisation problem (HSOP). This work is attempting to find an optimal pumping schedules that help minimise operational costs, satisfy the physical and hydraulic constraints of the network and maximise benefits of energy trading.

A team from the School of Mathematical Sciences were recently engaged by AEMO to provide expert advice on the metrics used to assess forecast accuracy that underpin their annual electricity consumption and of minimum/maximum half-hourly demand forecasts.

**Context Now**

South Australia is recognised globally as a leader in wind, solar and other renewable energy generation. It is also a world-leader in grid-scale and household-level battery storage. This global recognition has established the State as an investment destination for the development, testing and operationalisation of new renewable energy technologies and systems.

The State Government is focused on the future of energy in South Australia, and is active in attracting global energy companies to keep building the local renewable energy industry. The challenge we face as a state is the integration of the generators, distributors, storage assets and markets to create an affordable, reliable and resilient electricity market.

As energy generation becomes increasingly distributed, domestic households become energy traders, primary industry looks for localised energy solutions, and remote communities look to secure self-sufficiency. In this context, management of the energy grid requires complex systems modelling, optimisation and data-driven evidence to assist with the formation of policy and regulation.

Initiatives such as the Home Battery Scheme, Grid Scale Storage Fund and South Australian Virtual Power Plant Project are all examples of initiatives that will benefit significantly from modelling, optimisation, data analytics and machine learning to ensure their successful integration into the local and national energy grids and markets.

The Faculty of Engineering, Computer and Mathematical Sciences is well-placed to provide the data science expertise which holds the key to unlocking benefits at all stages along the energy value chain, from power generation to end consumers.
Sustainable energy is defined as a balanced composition between energy security and the four components of sustainability:
- Political acceptability;
- Economic development;
- Social equity; and,
- Environmental protection.

The pathway to a sustainable energy future is broader than the adoption of renewable resources and green technologies, rather it is a combination of reduced energy consumption from non-renewable resources, increased energy consumption from renewable resources, and increased energy efficiency on one side and creating positive economic and non-economic effects on the other.

It also includes the prediction of future factors that control the generation of this energy, possible events that disrupt availability and security, and its changing demand over space and time.

Relevant strategies that will help provide a sustainable energy future include the analysing, planning, directing, implementing, and control of sustainable energy generation, distribution and management.

As climatic patterns change, populations move and expand and new technologies replace old, the need to assess, predict and plan future scenarios is critical for ensuring energy.

Questions such as where to grow infrastructure, when are disruptive events most likely to occur and how can we design a system that can compensate for a catastrophic event are all critical considerations in ensuring a sustainable and resilient future energy network.

The advances in machine learning and artificial intelligence coupled with a new era in data generation and connectivity, society is now in the position to develop more accurate models and reliable future scenarios that can inform the future energy outlook globally. This research will help provide sustainable and resilient energy solutions for communities, cities and countries across around the world that have been developed to match local conditions, respond to disruptive events and support sustainable growth into the future.

Sustainable design also implies deployment of energy efficient solutions. Energy efficiency and conservation is a key part of our energy future roadmap and has an enormous impact on sustainability. Global
efficiency gains, since 2000, mitigated a 12% increase energy use in 2017 (IEA Energy Efficiency report, 2018) and this is equivalent to saving the need to install well over 1000 new large power stations. Many of these savings were achieved in the building and industry sectors.

Collaborations and Successes

Within the ECMS and the School of Civil, Environmental and Mining Engineering, the Intelligent Water Decisions Research Group (IWDRG) has considerable experience in assessing risk of complex systems to a broad range of natural hazards, including storms and floods, coastal inundation, fire, earthquake and heatwaves.

As part of the Bushfire and Natural Hazards CRC, the group has developed an integrated model and decision support system called UNHaRMED for Greater Adelaide, Greater and Peri-urban Melbourne, Tasmania and Greater Perth.

This technology can support the exploration of the impact of changes in population, the economy and the climate on the spatial and temporal distribution of future energy needs and production capacity.

To improve understanding of system dynamics and mitigate against unforeseen system failures, the group have also developed an open-source software tool called foreSIGHT for “stress testing” complex systems to a broad range of weather and climate scenarios, and using the outcomes of these tests to identify options to improve overall system resilience.

The group also maintains a long-term research partnership with the Bureau of Meteorology where the Bureau has operationalised University of Adelaide research tools to provide reliable and precise probabilistic seasonal forecasts at 400 sites Australia-wide. This forecasting enhances risk-based decision making for water supply, irrigation systems and ecological systems with additional application to forecasting renewable energy generation (solar and wind resources), and periods of higher infrastructure danger for response planning.

Context Now

The ability to predict energy demands at times of peak (and off-peak) usage is a critical component to the provision of electricity locally and nationally. This has significant implications for the management of State and National electricity grids as well as the energy market that governs supply and cost.

As a new generation of infrastructure emerges with the deployment of grid-scale energy generation (such as solar and wind) and storage systems (batteries and pumped hydroelectricity), the need to understand current and future climatic conditions, assess various disruptive events and develop responses to secure energy generation and delivery is critical to informing planning, technology and policy decisions.

At the domestic level, the integration of virtual networks through household solar and battery systems, population growth and geographical distribution of communities also requires decisions to be made around the most suitable technologies, climatic conditions, current and future infrastructure requirements and population growth.

We are now positioned with the opportunity to work with government agencies, energy generators and distributors, local councils and other research institutions to develop future energy scenarios that will help define the energy systems of the future. Utilising a range of environmental, technological, economic and social factors and drawing on a wealth historical and current data and information.

Energy systems are susceptible to a range of environmental and climatic events that can dramatically affect their output, operation and efficiency.

Predicting these events, as well as modelling potential system responses and developing mitigating strategies are critical to minimising supply disruption, effectively responding to events and preserving infrastructure.

Domain Lead

Professor Volker Hessel

Domain Experts

Professor Holger Maier; Professor Seth Westra; Professor Mark Thyer; Professor Peter McCabe; Professor Dmitri Kavetski; Professor Veronica Soebarto; Professor Jian Zuo; Dr Tim Lau; Dr Lei Chen
The rapid adoption of renewable energy over the last decade has seen a fundamental transformation in the way electricity is generated, distributed and stored.

The transition to a digitally integrated energy future requires the development of robust and trusted systems that are capable of integration through residential, local and national scales and resilient to disruptive events and breaches of security.

Energy Cybersecurity and Platforms research examines, assesses and designs systems will help deliver efficient and reliable energy management and ensure infrastructure security at the domestic, industry and grid scale.

**Domain Lead**
Professor Ali Babar

**Domain Experts**
Professor Hong Shen; Professor Cheng-Chew Lim; Professor Peng Shi; Professor Matthew Roughan; Professor Derek Abbott; Dr Matthew Sorell; Dr Yuval Yarom; Dr Hung Nguyen; Dr Mingyu Guo; Dr Chitchanok Chuengsatiansup; Dr Jason Xue; Dr Nguyen Khoi
This transformation has allowed consumers—from the domestic users through to industry and at grid-scale—to become energy generators in their own right and has given them more choice and control in the way they can consume power.

This transformation has also led to a more distributed electricity network, that is, a system comprised of multiple generators and consumers, at a range of scales and a geographical locations—for example, the use of roof top solar power systems.

Successfully managing this distributed network relies heavily on the integration of each individual component within the system, ensuring communication networks are secure and the management systems are reliable and responsive. For example, South Australia has been investigating the use of software systems to link a number individual energy generating and storage resources to create a Virtual Power Plant (VPP) to help manage demand peaks or sudden fluctuations in network capacity.

A new market has also risen around smart technologies and software solutions that allow consumers the ability optimise their electricity generation and storage capability and feed electricity into the grid for savings/profit.

This software and its connection with other parts of the grid represent a significant step forward in management efficiency but it also requires secure and reliable communication networks to ensure their resilience.

Collaborations and Successes

The University of Adelaide is the project lead for the recently announced Cyber Security CRC project Cyber Common Operating Picture (CCOP), A platform for Gather, Analyse, and Visualise Cyber Security Data. This project aims to build and rigorously evaluate new and novel approaches, metrics, and technological infrastructure that provides companies with a highly configurable and customisable platform for their cybersecurity operation.

The CCOP will work to improve company executives’ and managers’ understanding of their cyber security platforms and aid the technical and socio-technical decision making for addressing cyber security threats, vulnerabilities, and attacks.

In the energy sector, outcomes of the CCOP project include new knowledge and platforms that enabling the reporting of cybersecurity status and capabilities according to the World standards like Cyber Capabilities Maturity Model (C2M2).

Project partners include electricity, gas and solar retailer ACTewAGL and energy infrastructure company Jemena, as well as National Australia Bank, Trusted Security Services (TSS), and CSIRO/Data61.

Context Now

The first key outcome of the 2017 Independent Review into the Future Security of the National Electricity Market was the need for increased security of the National Electricity Market. This encompasses the reliability of the network, responsiveness to human and environmental events and the cyber security preparedness of all participants in the energy market.

In 2018 and in response to the review, AEMO in conjunction with industry and government partners has developed a cybersecurity framework for the Australian energy sector—the Australian Energy Sector Cyber Security Framework (AESCSF). The AESCSF leverages globally recognised cyber security frameworks to provide a foundation on which the sector can be consistently assessed with the resultant information helping uplift cyber security capabilities, and ultimately strengthen its cyber resilience.

On 11 July 2018, the Security of Critical Infrastructure Act 2018 also commenced, seeking to manage the complex and evolving national security risks of posed by foreign involvement in Australia’s critical infrastructure. The Act applies to approximately 165 assets in the electricity, gas, water and ports sectors.

The Critical Infrastructure Centre will assist in administering the Act, conducting risk assessments that examine:

• A company’s security policies, i.e. data security and physical security;
• Security audits undertaken by a company;
• Emergency management plans and redundancies; and,
• Offshoring and outsourcing of operations.

The secure systems, cybersecurity and complex network expertise within the University has an opportunity to work with industry in meeting this new level of infrastructure safeguarding.
APPENDIX 1 – DOMAIN EXPERTISE

1. Electrical Power Engineering
2. Energy Supply
3. Energy Vectors Generation and Utilisation
4. Energy Storage Solutions
5. Modelling, Optimisation and Machine Learning for Energy Systems
6. Sustainable Energy Systems Design
7. Energy Cybersecurity and Platforms
ELECTRICAL POWER ENGINEERING

Assoc. Prof Mike Gibbard
School of Electrical and Electronic Engineering
Power systems dynamics and control

Assoc. Prof Nesimi Ertugrul
School of Electrical and Electronic Engineering
Power and energy systems engineering, autonomous electric vehicles

Assoc. Prof Cornelius (Keith) Kikkert
School of Electrical and Electronic Engineering
Power systems communications, smart grid communications, powerline monitoring

Mr David Vowles
School of Electrical and Electronic Engineering
Large interconnected power systems and determination of power system limits

Mr Qi Ming Zhang
School of Electrical and Electronic Engineering
Small and large signal stability, power systems dynamics

Dr Ali Pourmousavi
School of Electrical and Electronic Engineering
Optimal stationery and mobile battery storage sizing, operation, and aggregation for power system applications, and ancillary services through demand response for the future smart grid.

Dr Said Al-sarawi
School of Electrical and Electronic Engineering
Wide bandgap semiconductor (WBS) power devices

Dr Andrew Allison
School of Electrical and Electronic Engineering
Energy conversion and electrical power, transformers, rotating machines, solar panels, batteries, and switching electronics. Statistical signal processing, and control.

Key Publications


Prof Graham (Gus) Nathan
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 the development of innovative technologies for process heat, power and fuels in partnership with industry.

He leads the Solar Fuels program in the $87M Australian Solar Thermal Research Initiative, which aims to lower the cost of solar fuels production by gasification of biomass residues and leads the $14M ARENA funded project to introduce concentrating solar thermal into the Bayer Alumina process. He has published more than 200 papers in leading international journals, 250 in peer-review conferences, 12 patents and 50 commissioned reports.

Professor Nathan has worked closely with industry throughout his career, with a 13-year industrial lectureship and undertaking more than 50 commissioned reports to industry. His past technology developments include being principal leader of the Chief Design Team for the award-winning fuel and combustion system for the Sydney 2000 Olympic Relay Torch and joint leadership of the development of low NOx combustion technology in rotary cement kilns.

He now specialises in the development of concentrating solar thermal hybrid technologies for applications spanning industrial process heat, solar fuels and power generation, with three platforms of patented technology.

Domain Experts

Prof Bassam Dally
School of Mechanical Engineering
MILD combustion/flameless oxidation, soot evolution in flames, combustion-solar car hybrid energy, effect of leading-edge protruberance of aerofoil performance, utilisation of VIV and WIV for energy generation, utilisation of bio-fuels for energy generation, turbulent reacting flows, heat transfer, computational fluid dynamics, laser diagnostics

Prof Benjamin Cazzolato
School of Mechanical Engineering
Wave and tidal energy

Assoc. Prof Eric Hu
School of Mechanical Engineering
Efficient combustion, clean combustion, executive member of the Centre of Energy technology

Prof Peter Ashman
School of Chemical Engineering and Advanced Materials
Biomass utilisation, bioenergy and solar thermal energy

Prof David Lewis
School of Chemical Engineering and Advanced Materials
Hydrotreatment liquefaction, sustainable solutions for managing waste streams. Fluid mechanics, thermodynamics, reaction kinetics, and process control.
Assoc. Prof Maziar Arjomandi
School of Mechanical Engineering
Ocean wave energy converter design, optimisation, control and techno-economic assessment. Deputy director & executive manager within the Australia-China Joint Research Centre of Offshore Wind & Wave Energy Harnessing

Assoc. Prof Zeyad Alwahabi
School of Chemical Engineering and Advanced Materials
Concentrated solar thermal for power generation, liquid fuel production and mineral processing, biomass gasification, high temperature thermal energy storage, process modelling and techno-economic assessment, torrefaction and pyrolysis

Assoc. Prof Paul Medwell
School of Mechanical Engineering
MILD (moderate or intense low oxygen dilution) combustion, solar energy

Assoc. Prof Boyin Ding
School of Chemical Engineering
Solar hybrid and geothermal systems

Dr Zhao Tian
School of Mechanical Engineering
Sustainable energy and waste management systems, including biomass combustion, pyrolysis and gasification with expertise in flue gas and synthesis gas analysis, biochar characterisation and utilisation of biochar for carbon sequestration and environmental applications.

Air pollution control and building energy efficiency. Energy efficient air purification system using catalytic combustion and adsorption for both industrial and domestic applications

Dr Woei Saw
School of Chemical Engineering and Advanced Materials
Utilisation of concentrated solar thermal energy in high temperature processes including gasification of solid fuels and calcination of minerals

Dr Philip Kwong
School of Chemical Engineering and Advanced Materials
Renewable energy, solar thermal energy, combustion science of fossil and alternative fuels, development/demonstration of clean energy technologies, reactor design, heat/mass transfer, aerodynamic, and multi-phase flows

Dr Philip van Eyk
School of Chemical Engineering and Advanced Materials
Solar thermal energy storage; carbon capture and storage; chemical looping technologies; energy systems and management; transport phenomena; thermos dynamics; multi-phase reactions

Dr Mehdi Jafarian
School of Mechanical Engineering
Fluid mechanics, turbulence, computational fluid dynamics, flow control, blood flow, UAI, rough wall flow, aerospace application

Dr Alfonso Chinnici
School of Mechanical Engineering
Carbon free fuels, reuse of residual heat, energy harvesting;

Dr Rev Chin
School of Mechanical Engineering
Turbulence, computational fluid dynamics, flow control, Heat transfer in pipe flows

Key Publications


Canton, J., Ortu, R., Chin, C., Schlatter, P., (2016), Reynolds number dependence of large-scale friction control in turbulent channel flow. Physical Review Fluids, 1 (8), 10.1103/PhysRevFluids.1.081501


ENERGY VECTORS GENERATION AND UTILISATION

**Prof Bassam Dally**

Professor Dally is the Deputy Director of the Centre for Energy Technology, CET, at the University of Adelaide. His research career and interests span a variety of energy related topics including, thermal science and engineering, renewable energy, renewable fuels and applied laser diagnostics.

His interest in energy vectors extends to hydrogen and ammonia, energy storage, hybrid energy systems and fuel adaptation to industrial processes. He is a co-inventor of two patents related to energy and has attracted in excess of $20 million in research grants along with his colleagues. He has contributed to many public fora related to energy, co-authored three major review papers and more than 270 research papers in energy related topics.

Prof Dally has received many awards over the years, and in 2016 he was named “Energy Professional of the Year” by the SA Branch of the Australian Energy Institute.

**Domain Experts**

**Prof Shizhang Qiao**

School of Chemical Engineering and Advanced Materials  
Catalysts, nanomaterials and nanoporous materials for new energy technologies (electrocatalysis, photocatalysis, batteries, fuel cell, supercapacitors)

**Prof Graham (Gus) Nathan**

School of Mechanical Engineering  
Biofuels, hydrogen

**Prof Peter Ashman**

School of Chemical Engineering and Advanced Materials  
Biomass utilisation, bioenergy and solar thermal energy

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**Prof Volker Hessel**

School of Chemical Engineering and Advanced Materials  
Ammonia

**Assoc. Prof Paul Medwell**

School of Mechanical Engineering  
MILD (moderate or intense low oxygen dilution) combustion, solar energy

**Dr Mehdi Jafarian**

School of Mechanical Engineering  
Fluid mechanics, turbulence, computational fluid dynamics, flow control, blood flow, UAV, rough wall flow, aerospace applications

**Dr Aihrea Z Salmachi**

Australian School of Petroleum and Energy Resources  
Flow modelling in porous media, drilling and well completion engineering, production data analysis

**Dr Neil Smith**

School of Chemical Engineering and Advanced Materials  
Liquid fuels, energy pipelines

**Key Publications**


ENERGY STORAGE SOLUTIONS

Prof Angus Simpson
Professor Simpson has been at the University of Adelaide for 32 years. His research interests include the simulation modelling and optimisation of the planning, design and operation of water distribution system infrastructure (including pumping systems). He has written 150 refereed journal articles in leading International Journals and more than 160 conference papers. In the energy space, since 1998 he has been involved in the optimisation of water pumping by considering the water-energy nexus. A genetic algorithm framework has been developed to optimise both tank water trigger levels for pump operations as well as pump scheduling over a period of future time in order to minimise the cost of pumping for a multi-part peak/off-peak electricity energy tariff. More recently his research has involved the techno-economic evaluation of hydropower projects to be installed within existing water utility infrastructure. Pumped hydroelectricity evaluation and optimisation are also beginning to become a focus of his research. Another aspect of consideration of the water-energy nexus in terms of using water storages has involved the optimisation of operation of pumping and hydroelectric energy generation while purchasing or selling electrical energy on the AEMO one-half hour spot price market. This research is being carried out jointly with Prof. Erik Weyer of Electrical Engineering at the University of Melbourne.

Domain Experts

Prof Shizhang Qiao
School of Chemical Engineering and Advanced Materials
High performance lithium ion batteries and supercapacitors, nanomaterials for new energy conversion and storage technologies (electrocatalysis, photocatalysis, batteries, fuel cell, supercapacitors).

Prof Shaobin Wang
School of Chemical Engineering and Advanced Materials
Nanomaterial synthesis and application for adsorption and catalysis, fuel and energy conversion and environmental remediation.

Prof Graham (Gus) Nathan
School of Mechanical Engineering
Hydrogen storage

Prof Dusan Losic
School of Chemical Engineering and Advanced Materials
Materials for supercapacitors, synthesis of functional materials and surfaces with anodimensions including graphene and 2d materials

Prof Peter Ashman
School of Mechanical Engineering
Energy storage

Prof Bassam Dally
School of Chemical Engineering
Hydrogen storage

Prof Martin Lambert
School of Civil, Environmental and Mining Engineering
Modelling of hydroelectric energy generation systems

Assoc. Prof Nesimi Ertugrul
School of Electrical and Electronic Engineering
Battery storage, Energy Storage Solutions

Assoc. Prof Maziar Arjomandi
School of Mechanical Engineering
Thermal and mechanical energy storage systems including pumped-hydro and pressurised membranes, thermo-chemical energy storage systems including hydrogen and syngas production, phase-change materials, nano- and micro-fluidic systems, modelling of energy storage solutions


Energy capability within the Faculty of Engineering, Computer and Mathematical Sciences


Dr Andre Costa
Dr Costa is currently Director of the Teletraffic Research Centre (TRC) within the Faculty of Engineering, Computer and Mathematical Sciences at The University of Adelaide. He has 15 years’ experience in the commercial application of mathematical and statistical models and has held industry roles in data science, statistical consulting, mathematical finance, risk modelling and operations research. Andre has delivered end-to-end projects from conception to user-facing products in a range of industries including telecommunications, utilities and energy. Prior to his career in industry, he was a post-doctoral research fellow at the Centre for Excellence in Mathematics and Statistics of Complex Systems at the University of Melbourne. Andre gained his PhD in Applied Mathematics from The University of Adelaide in 2003, in the field of biologically-inspired adaptive ant-based routing algorithms for telecommunications networks.

Domain Experts

Prof Nigel Bean
School of Mathematical Sciences
Stochastic modelling

Prof Joshua Ross
School of Mathematical Sciences
Stochastic modelling

Prof Holger Maier
School of Civil, Environmental and Mining Engineering
Genetic algorithms

Prof Angus Simpson
School of Civil, Environmental and Mining Engineering
Genetic algorithms

Prof Seth Westra
School of Civil, Environmental and Mining Engineering
Climate risk and statistical modelling

Prof Pavel Bedrikovetski
Australian School of Petroleum and Energy Resources
Mathematical modelling, laboratory studies and field projects in coal seam gas reservoirs; shale gas fields; geothermal fields; waterflooding; Low-Sal and Smart waterflooding; EOR; formation damage

Assoc. Prof Quinfeng (Javen) Shi
School of Computer Science
Machine learning

Assoc. Prof Manouchehr Haghighi
School of Computer Science
Simulation and optimization of multi-stage hydraulic fracturing in shale and tight gas reservoirs

Dr Ali Pourmousavi Kani
School of Electrical and Electronic Engineering
Simulation and optimization of multi-stage hydraulic fracturing in shale and tight gas reservoirs

Dr Markus Wagner
School of Computer Science
Renewable energy; wind farms; bio-inspired optimisation; heuristic search; algorithm design; multi-objective optimisation

Dr Paul Dalby
Australian Institute for Machine Learning
Machine learning

Dr Mohammad Sayyafzadeh
Australian School of Petroleum and Energy Resources
Applied and computational mathematics targeting reservoir and production engineering problems including history matching, field development optimisation and uncertainty quantification

Dr Abbas Zeinijahromi
Australian School of Petroleum and Energy Resources
Mathematical and laboratory modelling of suspension flow in porous media, low salinity water flooding, formation damage, and applications of nano-particles in enhanced recovery

Mrs Maria Gonzalez Perdomo
Australian School of Petroleum and Energy Resources
Petroleum production technology, reservoir engineering, hydraulic fracturing and production optimisation, evaluating and optimising conventional and unconventional resources

Key Publications


In 2005 and 2011, Prof. Hessel was appointed as part-time and full professor at Eindhoven University of Technology, the Netherlands, respectively. In 2018, he was appointed at the University of Adelaide, Australia, as Deputy Dean (Research) at ECMS Faculty and Prof. Pharmaceutical Engineering. He was honorary professor at TU Darmstadt, Germany 2009–2018, and is guest professor at Kunming University of Science and Technology, China (2011–present).

Prof. Hessel holds > 480 peer-reviewed articles with h-index 60. He received the AIChE Award “Excellence in Process Development Research” in 2007, the ERC Advanced Grant “Novel Process Windows” in 2010, the ERC Proof of Concept Grant in 2017, the IUPAC ThalesNano Prize in Flow Chemistry in 2016, and the FET OPEN Grant in 2016.


Domain Experts

Prof Holger Maier
School of Civil, Environmental and Mining Engineering
Sustainable management of infrastructure—with a particular focus on water, energy and the water-energy nexus, modelling, optimisation and decision support

Prof Seth Westra
School of Civil, Environmental and Mining Engineering
Climate risk and statistical modelling

Prof Mark Thyer
School of Civil, Environmental and Mining Engineering
Bayesian methods

Prof Peter McCabe
Australian School of Petroleum and Energy Resources
Unconventional resources, architecture of sandstone reservoirs for oil and gas, sequence stratigraphy of non-marine strata, Depositional environments of coal and coal-bearing strata, assessment of fossil fuel resources


Prof Ali Babar

Professor M. Ali Babar is a Professor in the School of Computer Science, University of Adelaide. He is an honorary visiting professor at Nanjing University, China. Prof Babar established an interdisciplinary research centre, CREST—Centre for Research on Engineering Software Technologies, where he leads a research group of more than 20 members. Since November 2013, he has attracted a significant amount of research resources that include A$5.5 million in funding from organisations such as Cyber Security CRC, Defence Science and Technology (DST) Group, CSIRO/Data61, and Data to Decision (D2D) Cooperative Research Centre (CRC).

Prof Babar led the University of Adelaide’s participation, involving 14 researchers from six schools, in a successful bid for setting up a Cyber Security Cooperative Research Centre (CSCRC), whose estimated budget is around A$140 million over seven years with A$50 million provided by the Australia government. Prof Babar leads the theme on Platform and Architecture for Cyber Security as a Service. Prof Babar has authored/co-authored more than 210 peer-reviewed publications through premier software technology journals and conferences.

In addition to his work having several industrial R&D projects and setting up a number of collaborations in Australia and Europe with industry and government agencies, his publications have been highly cited within the Software Engineering discipline with an h-index = 46 with >8000 citations as per Google Scholar in November, 2019.
Domain Experts

Prof Hong Shen
School of Computer Science
Privacy preserving computing

Prof Cheng-Chew Lim
School of Electrical and Electronic Engineering
Privacy for energy trading on smart grid, smart metering, and IoT

Prof Peng Shi
School of Electrical and Electronic Engineering
Privacy for energy trading on smart grid, smart metering, and IoT

Prof Matthew Roughan
School of Mathematical Sciences
Network security, network measurement, network management, stochastic modelling, probability, statistics, and data science

Prof Derek Abbott
School of Electrical and Electronic Engineering
Authentication, noise-based security, game theory, stochastic methods

Dr Matthew Sorell
School of Electrical and Electronic Engineering
Stochastic methods

Dr Chitchanok Chuengsatiansup
School of Computer Science
Algorithmic game theory methods for security

Dr Mingyu Guo
School of Computer Science
Provable network security

Dr Hung Nguyen
School of Computer Science
Certificateless cryptography

Dr Jason Xue
School of Computer Science
Machine learning, security and privacy, system and software security, internet measurement and fraud detection

Dr Nguyen Tran
School of Computer Science
Data analytics, web of things

Key Publications


While the use of renewable energy resources for electricity generation has grown rapidly in Australia over the last decade, the vast majority of the energy consumed in Australia (92.3%) still comes from fossil fuels (oil – 37%; gas – 24.7%; and coal – 30.7%).

Although there has been a decline in coal consumption over the last decade, there has been a substantial growth in oil and gas consumption – on an annual basis the growth in petroleum (oil and gas) consumption in recent years has averaged more than four times that of renewable fuels.

The national economy is strongly dependent on fossil fuels – they comprise 26% of Australia’s total exports. Major markets for Australia’s energy resources include Japan, China and South Korea. Australia is the world’s largest exporter of both LNG (natural gas shipped by tanker) and coal, which is used for both iron and steel manufacturing as well as electrical generation.

Coal is the nation’s top export. Natural gas export (via LNG) is growing rapidly and currently are the third largest export. The annual net value of the trade balance in fossil fuels is A$79 Billion.

Current major areas of oil and gas production in Australia include the Cooper Basin in South Australia, the Gippsland Basin offshore Victoria, the Northwest Shelf offshore Western Australia and the Surat and Bowen Basins of Queensland.

Current exploration in areas such as the Great Australian Bight and the Beetaloo Basin in the Northern Territories suggest that they contain world-class petroleum resources that have the potential to significantly boost the nation’s oil and gas production. Major coal-producing areas are in Queensland and New South Wales.
The Australian School of Petroleum and Energy Resources is a world-class institution for petroleum education, training and research. It is Australia's only multidisciplinary school serving the petroleum sector. Research capabilities within the school encompass petroleum engineering, petroleum geoscience, carbon storage, and decision-making related to oil and gas exploration and production that are applied both on a national and international scope. The school has particular expertise across the following areas:

- Normative and behavioural approaches to decision making;
- Formation damage and enhanced oil-gas recovery;
- Petroleum engineering;
- Petroleum geoscience;
- Stress, structure, and seismic analyses.

**Normative and Behavioural Approaches to Decision Making**

Our normative and behavioural approaches to decision-making researchers are particularly focused on financial investment decisions, along with economic and psychological approaches to understanding and improving industry decisions. These include:

- Applying decision analytic techniques to complex decision problems;
- Developing economic evaluation methods to account for uncertainty;
- Developing improved processes for eliciting expert estimates;
- Identifying barriers to good decision-making;
- Developing debiasing strategies to mitigate these problems; and,
- Psychometric analyses.

**Formation Damage and Enhanced Oil-Gas Recovery**

Our formation damage and enhanced oil-gas recovery research examines various forms of modelling to control and enhance the flow, migration and recovery of hydrocarbon resources. The research group is particularly focused on modelling:

- Advanced oilfield waterflood techniques;
- Chemical enhanced oil recovery;
- CO2 geo-sequestration in aquifers and oilfields;
- Well stimulation in coal-bed methane fields; training and research;
- Shale-gas field development;
- Drilling fluid design;
- Suspension-colloidal-nano transport in porous media;
- Exact and asymptotic solutions for flow in porous media;
- Nano technologies in oil and gas production;
- Well injectivity and productivity;
- Formation damage and skin; and,
- Oil and gas secondary migration.

**Petroleum Engineering**

Petroleum Engineering is the practical application of physics, mathematics, chemistry and geology, combined with economic principles, to the recovery of petroleum.

Our Petroleum Engineering research is strongly guided by real-world industry needs, focusing on areas such as waterflooding, reservoir simulation, and enhanced oil and gas recovery for conventional and unconventional resources. Our work is particularly relevant to:

- Oil and gas service companies;
- Chemical suppliers;
- Environmental industries;
- Geothermal energy;
- Industrial waste disposal;
- Aquifer contamination; and,
- Vadose zone engineering.

**Petroleum Geoscience**

Petroleum Geoscience concerns the exploration, recovery, development and management of subsurface energy resources. Our Petroleum Geoscience research is focused on:

- Fundamental geological processes;
- The geophysical methodologies required to discover and produce hydrocarbon resources;
- Development of fundamental technical and workflow advances.

Our Petroleum Geoscience work is of particular value to a wide range of companies and researchers interested in:

- Petroleum exploration and development;
- Carbon capture and storage;
- Engineered geothermal systems;
- Sedimentary basin-hosted mineral deposits;
- Groundwater use and extraction; and,
- Shallow and deep coal-seam gas production.

**Stress, Structure and Seismic**

The Stress, Structure and Seismic research group seeks to understand key tectonic processes in sedimentary basins, and identify and recover petroleum, geothermal and unconventional resources.

Our researchers—petroleum geoscientists and engineers—integrate expertise in petroleum geomechanics, tectonics and neotectonics, structural geology, basin evolution and dynamics, and seismic interpretation. Research within the group is particularly focused on:

- Constraining contemporary and ancient crustal stress fields’ nature and origin;
- Predicting fault and fracture-controlled fluid flow away from the wellbore;
- Understanding how detachment zones control deformation styles in fold-thrust belts; and,
- Constraining intrusive and extrusive magmatism’s impact on hydrocarbon prospectivity.

**About the School**

More information on the Australian School of Petroleum and Energy Resources can be found on the School website: ecms.adelaide.edu.au/petroleum-engineering/our-research
APPENDIX 3 — KEY INSTITUTES AND CENTRES
The Institute for Mineral and Energy Resources

The Institute for Mineral and Energy Resources (IMER) is the University’s principal point of contact for mineral and energy resources research, including industry and government partnerships. IMER’s key role is to assemble interdisciplinary teams from the University of Adelaide and research partners to address global challenges in

• Deep Resources;
• Deep Mining;
• Complex Processing;
• Tight Energy Resources; and
• Low Cost, Low Emissions Energy.

At IMER, we have more than 140 of the world’s experts to help you innovate and push past challenges in your business. Our strengths are in geology, geophysics, petroleum engineering, mining engineering and energy technology.

The Institute for Mineral and Energy Resources (IMER) is tasked with addressing the grand challenge in minerals and energy facing Australia and the world: maintaining industry growth in an economically, socially and environmentally sustainable manner.

IMER uses its extensive and deep understanding of the technologies, trends, issues and challenges facing industry to undertake strategic initiatives. These involve strong industry engagement; creating practical industry collaborations; delivering new and innovative products, processes and services; and delivering meaningful, long-term positive impacts for industry and society.

The Centre for Materials in Energy and Catalysis

The Centre for Materials in Energy and Catalysis (CMEC) is a materials-engineering research leader, developing new materials and catalysts to enable positive social, environmental and economic impact.

South Australia is internationally renowned as a leader in renewable energy. CMEC is committed to maintaining and enhancing the state’s profile in this globally critical sector through research that facilitates a cleaner, greener future.

Headed by ARC Laureate and highly cited researcher Professor Shizhang Qiao, CMEC leads the way in novel materials development for energy and catalytic applications, through both fundamental and applied research.

CMEC contributes to Australia’s international standing in new energy and catalysis technologies. We develop novel advanced materials and catalysts—and innovative approaches to their use—to achieve greater efficiencies and cost-effectiveness, and minimise environmental impact.

Our interdisciplinary and cooperative environment enables us to conduct cutting-edge research and perform activities in the field of materials for energy and catalysts.

Our current areas of focus include:

• Energy storage and catalysts;
• Electro-catalysis;
• Solar energy;
• Modelling;
• Hetero-catalysis;
• Bio-catalysis.

The South Australian Centre for Geothermal Energy Research

The South Australian Centre for Geothermal Energy Research (SACGER), a part of the Institute for Mineral and Energy Resources, researches enhanced (engineered) geothermal systems and power systems to improve the economic and environmental delivery of geothermal energy. This research offers widespread benefits for industry, the community and the environment. Our research areas include:

• Geophysical tools: novel approaches for understanding the distribution of subsurface permeability including using 3D seismic data and the development of magnetotelluric tools that are sensitive to the presence of fluid-filled fracture systems;
• Fluid rock interactions: the geochemistry of geothermal fluids using flow-through and batch hydrothermal reactors to evaluate the dissolution of reservoirs rocks and resultant precipitation and scaling within the subsurface reservoir and above ground infrastructure;
• Fracture modelling: development of reservoir fracture models for enhanced geothermal systems and improved understanding of fluid flow and heat transfer in rock fractures;
• Crustal stress characterisation: modelling contemporary crustal stresses in a number of regions around the world including areas of know geothermal potential such as the Cooper and Otway Basins, understanding the stress and fluid-pressure state in non-conventional geothermal systems.
The Faculty of Engineering, Computer and Mathematical Sciences is committed to delivering outstanding research that helps solve complex global problems and contributes to national priorities. We address global needs in collaboration with industry, government and the broader community.

Our expertise spans the following six research themes.

- Advanced Materials and Manufacturing
- Energy, Resources and Environment
- Food, Water and Agriculture
- Medical, Health and Bioprocessing Technologies
- Space and Defence
- Smart Technologies and Mathematics
Our Energy, Resources and Environment researchers possess world-class expertise in energy technology and efficiency, mining and petroleum engineering, and geoscience.

This expertise is applied collaboratively to develop innovative, value-adding technologies that help transform the global energy and resource industries. Areas of focus and research strength include:

- Solar thermal;
- Power control;
- Management and modelling systems;
- Developing new, cost-effective methods for removing non-target metals from copper concentrates;
- Resource engineering to address challenges associated with deep mining activities;
- Understanding and unlocking Australia’s future resources base, including low-carbon gas and geothermal energy sources.

Our Energy, Resources and Environment research helps industry generate more—and cleaner—energy and resources, and store and supply them in a stable, environmentally friendly manner, whilst accelerating society’s transition to carbon neutrality.

More information can be found at: https://ecms.adelaide.edu.au/research-impact/energy-resources-environment

**University-Wide Capability**

The Faculty of Engineering, Computer and Mathematical Sciences maintains strong links across the University of Adelaide through its research groups, schools, and centres. Key research collaborators include:

**Professor Paul Babie**  
Adelaide Law School  
*Climate change and resources*

**Dr Douglas Bardsley**  
Geography, Environment and Population  
*Environment and public policy*

**Dr Raul Barreto**  
School of Economics  
*The effect of energy sources on economic growth*

**Dr Fran Binenbaum**  
School of Economics  
*Science and technology policy*

**Dr Karlson (Charlie) Hargroves**  
Entrepreneurship, Commercialisation and Innovation Centre (ECIC)  
*Sustainable engineering, energy efficiency, climate change policy*

**Professor Martin Hand**  
School of Physical Sciences  
*Geo thermal energy*

**Professor Richard Hills**  
Division of Research and Innovation  
*Mineral exploration technologies, petroleum geomechanics, geothermal energy*

**Professor Graham Heinson**  
School of Physical Sciences  
*Monitoring of hydrocarbon and geothermal fluids*

**A/Professor David Huang**  
School of Physical Sciences  
*Catalysis, gas separation*

**A/Professor Tak Kee**  
School of Physical Sciences  
*Organic solar cells*

**A/Professor Rosalind King**  
School of Physical Sciences  
*Petroleum geomechanics*

**Mr Paul Leadbeter**  
Adelaide Law School  
*Pollution control law and environmental regulation of the mining industry*

**Professor Stephen Lincoln**  
School of Physical Sciences  
*Solar energy*

**Dr Virginie Masson**  
School of Economics  
*Energy economics, effects of demand management*

**Professor Greg Metha**  
School of Physical Sciences  
*Catalysts for energy production*

**Dr Cameron Shearer**  
School of Physical Sciences  
*Photovoltaics, hydrogen production*

**Professor Christopher Sumby**  
School of Physical Sciences  
*Energy storage, energy waste management, catalysts, and nanoporous materials for gas separation*

**Dr Alex Wawryk**  
Adelaide Law School  
*Renewable energy regulations, wind energy law, oil and gas law, mining and the environment.*

**Professor Mike Young**  
Centre for Global Food and Resources  
*Environmental policy, water policy*

**Professor Ralf Zurbruegg**  
Adelaide Business School  
*Pricing and volatility dynamics*

**Professor David Ottaway**  
School of Physical Sciences  
*Airborne detection of methane, pipe leak detection*

**Professor Andre Luiten**  
School of Physical Sciences  
*Sensors for monitoring safety, efficiency, recharging processes, extraction, processing etc.*

**Professor Heike Ebendorff-Heidepriem**  
School of Physical Sciences  
*Sensors for monitoring safety, efficiency, recharging processes, extraction, processing etc.*