
Annual Report
2015
Genes to Energy | Energy to Yield
plant energy biology
ARC CENTRE OF EXCELLENCE

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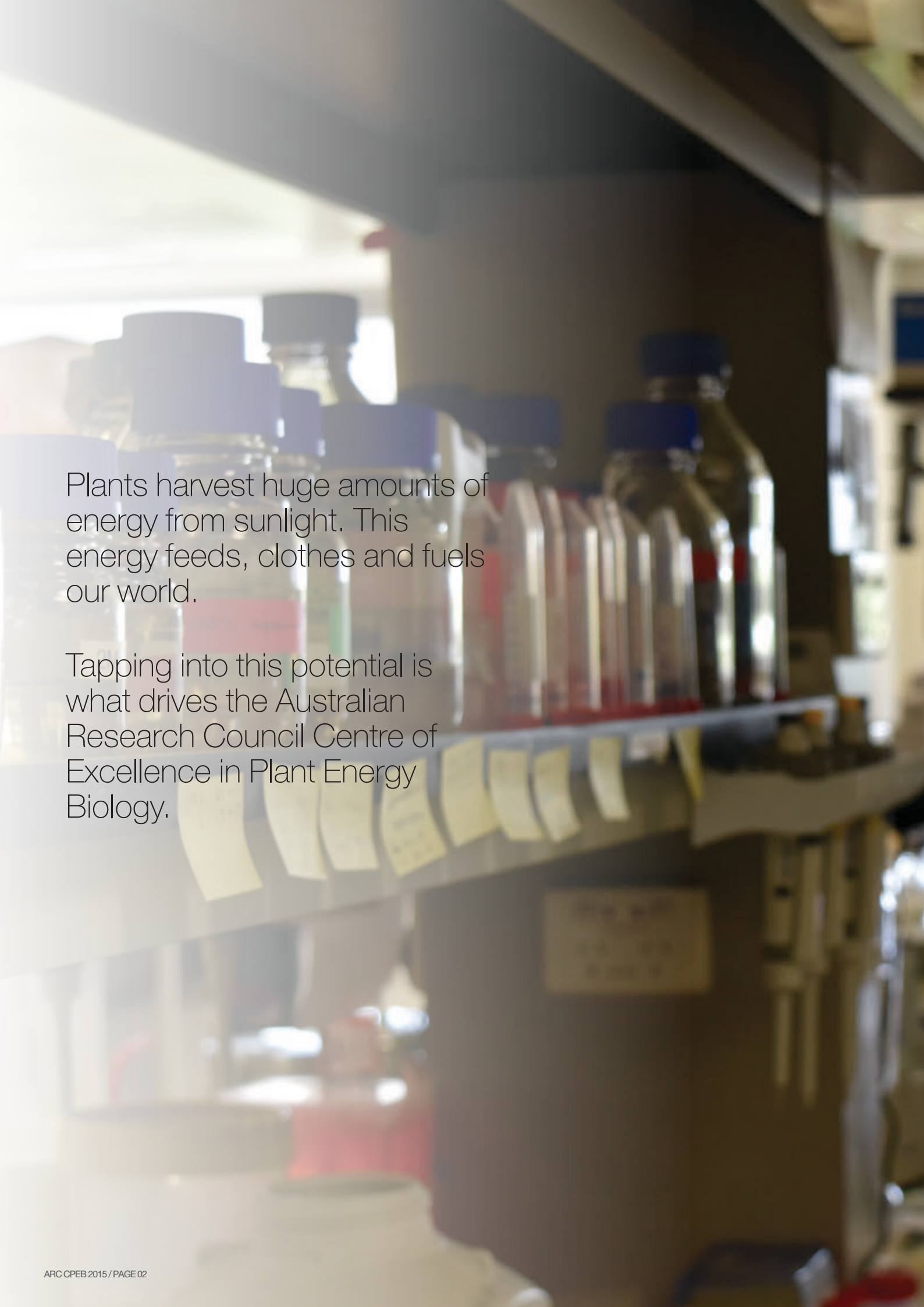


Plants harvest huge amounts of energy from sunlight. This energy feeds, clothes and fuels our world.

Tapping into this potential is what drives the Australian Research Council Centre of Excellence in Plant Energy Biology.

The Centre

Centre Overiew

The Australian Research Council Centre of Excellence in Plant Energy Biology (PEB) is focused on better understanding the way in which plants capture, convert and use energy in response to environmental change, with a view towards improved plant energy efficiency.

Vision

To enhance plant energy efficiency by simultaneously optimising energy capture, conversion and use in changing environments, in order to improve the sustainable productivity of plants.

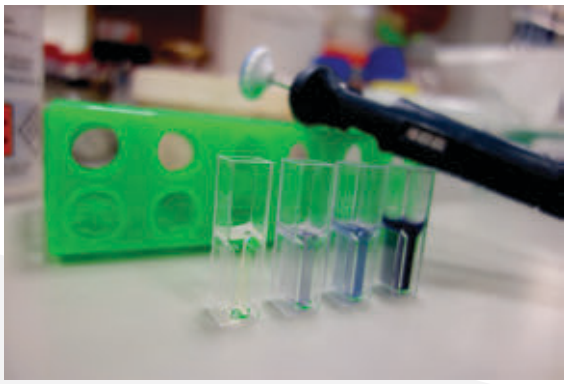
Mission

- Define the complex system that determines overall energy efficiency in plants.
- Discover the key signals, 'gatekeeper' cells, and (epi)genetic controls that regulate this energy system.
- Manipulate these regulators in combination to optimise energy efficiency across the whole plant and enhance yield.

Strategic Priorities

- To elucidate the fundamental mechanisms of energy biology regulation in plants.
- To be a leading Centre for advanced training and education for plant and computational biologists, in Australia.
- To build strategic collaborations for Australia within the international science community.
- To enhance plant biotechnologies in order to build technological innovations and aid Australian agricultural innovation.

Across Australia, a dedicated team of PEB researchers are focused on better understanding plant energy systems.



Plant Energy Biology Fast Facts 2015

- 4 collaborating universities; The University of Western Australia (administrating organisation), Australian National University, The University of Adelaide and La Trobe University.
- 10 Chief Investigators.
- 8 Partner Investigators in USA, Germany, Finland, Sweden and China.
- Partnerships with the Grain Research and Development Corporation, Agilent Technologies, Photon Systems Instruments and Groupe Limagrain.
- Over 130 internationally competitive staff and students.
- $26 million from the Australian Research Council and $14 million from partner universities and companies to fund the Centre through to 2020.
- Centre authors contributed to almost 90 publications in 2015.

Addressing a critical problem

The world faces three interconnected threats to food security: limited agricultural resources (land, water and key nutrients), a rising human population and per capita food consumption, and a yield gap resulting from reduced productivity of crops due to mismatches between crop genetics and unpredictable environments.

Plant function is complex. Current international research aims to optimise single-input processes, such as photosynthetic rate or nutrient uptake, in order to increase plant productivity. However, changing inputs alone can reduce the efficiency of downstream processes and thus limit their effectiveness.

PEB recognises that increasing overall 'plant energy efficiency' – the efficiency not only of energy capture, but also of energy conversion and use by plants in order to produce yield – is key to long-term food security.

The Centre aims to increase the efficiency of energy capture, conversion and use by plants by improving their ability to allocate resources and their tolerance to environmental challenges. Adding efficiency gains together via molecular signalling and control will increase crop plant productivity.

This approach to improving the sustainable productivity of plants will aid in future-proofing food production for Australia and the world.

An innovative research plan

PEB proposes a novel approach to improve sustainable plant yield by optimising their overall efficiency of energy capture, conversion and use. Rather than optimising single nutrient inputs or product outputs, targeting complex processes including plant metabolism, transport, and development for efficiency gains to will be more effective at enhancing overall plant productivity.

Improving multiple parameters simultaneously is a necessary solution to the increasing demand for more crop yield from finite land, water, and nutrient resources. Unpredictable environmental challenges adversely affect plant growth and further perturb plant energy balance, also limiting yield.

The epigenetic controls, gene variants and signals discovered by the Centre will provide a new basis for creating sustainably productive crops that can weather changing and challenging climates.

The enhancement of plant energy efficiency is being approached by PEB through three Research Programs which combine to translate molecular insights into whole plant performance.

These three programs are:

- **P1:** Energy metabolism and signalling
- **P2:** Gatekeeper cells and specialisation
- **P3:** Gene variants and epigenetics

A collaborative effort

The Centre brings together a collection of the world's best researchers from complementary disciplines and integrates scientific research across the range of scales required to truly address the different aspects of the energy efficiency challenge in plants.

Collaborations across Universities and with Industry Partners avoids "reinvention of the wheel" and draws on existing expertise. Sharing our research keeps it at the cutting edge and builds an international network for its application to real world solutions.

The Director's View

In 2015 the Centre of Excellence in Plant Energy Biology continued its challenging research agenda for the second of its seven years of funding from the Australian Research Council.

Our ten chief investigators, many new Centre staff and affiliates, and our growing team of students have been working hard to build our research programs and expand our partnerships.

Excellence in science is about refining our ideas and expertise until we find unexpected solutions for difficult problems. So what have we achieved in 2015?

Enhancing our Research Programs

Three research programs provide a strategic focus to our core research and ensure that our novel discoveries are met with an eye to their impact and application, both within and outside the bounds of plant science.

In the pages of this report we have sought to show the ideas, the discoveries and the personalities that enable data to become knowledge and knowledge to become innovations in these programs. We see this progression in our work on PPR proteins that control organelle genome expression, the signals that communicate the state of the cell in harsh and changing environments and the network of transporters that enhance plant nutrition and maximise salinity and drought tolerance.

Mapping the genes that govern energy efficiency in plants will help shape genome scale breeding approaches for the future.

Attracting the very best young scientists

The Centre's core research is extended by new researchers joining our team and pursuing novel ideas. This maximises the use of the exciting intellectual environment and the modern facilities at each of our university nodes.

The continued injection of new ways of solving problems and exciting expertise is the fuel that grows our Centre.

2015 has been an extraordinary year of growth with ten new research fellowships from Australian and European agencies awarded to early career researchers to join different Australian nodes of the Centre - Caitlin Byrt and Stefanie Wege (The University of Adelaide), David Secco, Bernard Gutmann, Brendan O'Leary, Aimone Porri, Alex de Mendoza and Sam Buckberry (The University of Western Australia), Steven Eichten (The Australian National University) and Reena Narsai (La Trobe University).

In addition Laura Boykin was awarded funding from the Bill and Melinda Gates Foundation to undertake her white fly genomics research in the Centre to help save African cassava farming. These Fellows join the Centre's growing list of staff and have begun their own programs to complement our research and expand the application of our expertise to new areas of biology. We look forward to everything that these enthusiastic researchers will continue to bring!

Training PhD students for an exciting future

There has never been a more exciting time to begin a scientific career in plant sciences. There is a clear momentum towards an integrated molecular understanding of biological systems that will make this generation of researchers the first to see the complexity of biology laid out in numbers.

Models and predictive biology will sit alongside wet-lab experiments and students will learn to enhance their mathematics and computing skills to explore their findings more powerfully.

At the same time as data analysis is more demanding there are clear imperatives to rapidly use data to mitigate the combined effects of changing climates and food security challenges.

Today's students will be tomorrow's researchers and will need new skills to work smart, to work together and to seek the support of both government and industry to fund their journeys of innovation. The training of the 50 PhD, Honours and Masters students currently in the Centre is a key part of our contribution to future innovation.

Performance and research impact

The Centre's publications remain in the top plant science and general science journals. Using citations as a metric, the Centre rivals many of the world's best known and respected plant science Centres, and Centre investigators are in demand as presenters at international conferences.

This year has seen Ian Small elected Fellow of the Australian Academy of Science, Barry Pogson recognised for the first time as a Thomson Reuters High Cited Researcher and Jim Whelan recognised by the Zhejiang Provincial Government for his research collaborations in China.

Two of our early-career researchers were Tall Poppy awardees in their State and our staff, affiliates and students won awards from science societies and their Universities for their papers, discoveries and presentations.

The Centre rightly prides itself not only on excellent science coming from its labs, but also strives to make sure that its discoveries are relevant to society. Partnerships with industry in 2015 have developed rapidly to enable phenomics of energy traits in wheat, new plant hybrid systems and biotechnology to enhance plant nutrition.

A series of Centre researchers, lead by Barry Pogson, were awarded an International Wheat Yield Partnership Grant in late 2015 to identify genes for energy use efficiency in wheat. We look forward to this project developing in 2016 and using the Centre's expertise to build new partnerships.

Professor Harvey Millar
Director

We will discover the interconnected molecular processes that limit how plants perform in variable environments to gain the sustainable increases in plant yield that are needed for the future.

Our Chief Investigators

PROFESSOR HARVEY MILLAR
(DIRECTOR)

Harvey's research aims to understand the role of respiration in primary carbon and nitrogen metabolism in plants, plant response to oxidative stress and the dynamics of plant proteomes under limiting conditions. Harvey is Centre Director and an ARC Future Fellow. In 2015 Harvey was named amongst the world's most highly cited researchers.

PROFESSOR IAN SMALL

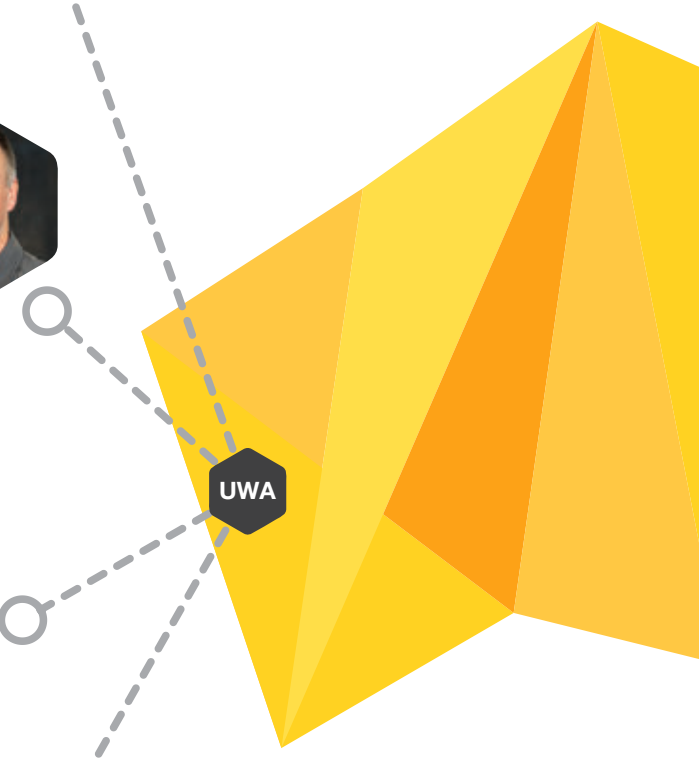
Ian's research interests involve understanding how plants coordinate the expression of nuclear and organellar genes, and building computational models of plant metabolism. Ian is an ARC Laureate Fellow and a Fellow of the Australian Academy of Science. He was also Western Australia's 2014 Scientist of the Year and named one of the world's most highly cited researchers in 2015. He co-leads Research Program 1 with Barry Pogson.

PROFESSOR RYAN LISTER

Ryan's research focus lies in plant and animal epigenomics. Ryan was named Life Scientist of the Year at the 2014 Australian Prime Ministers awards. He co-leads Research Program 3 with Justin Borevitz.

PROFESSOR RANA MUNNS

Rana's focus is on the mechanisms by which plants adapt to drought and salinity stress. Rana holds a joint position with the University of Western Australia and CSIRO Agriculture, Canberra. Rana is a Fellow of The World Academy of Sciences and is recognised internationally for her insights into the fundamental principles of crop adaptation to salinity, and for applications of these insights.

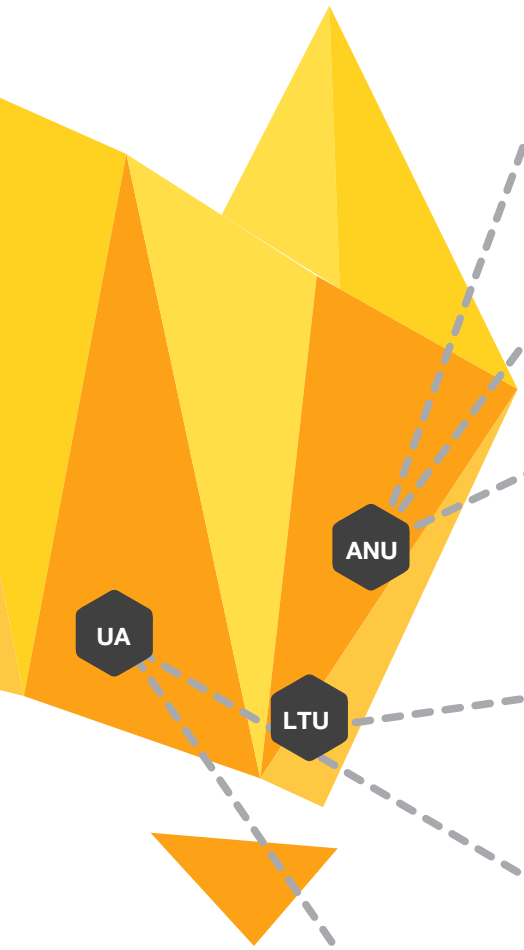


UWA | UNIVERSITY OF WESTERN AUSTRALIA

ANU | AUSTRALIAN NATIONAL UNIVERSITY

UA | UNIVERSITY OF ADELAIDE

LTU | LA TROBE UNIVERSITY



PROFESSOR BARRY POGSON
(DEPUTY DIRECTOR)

Barry's research looks into defining novel roles for carotenoids in plant developmental processes, with complementary research into organelle signalling to identify the mechanisms by which plants perceive and respond to drought and excess light. He in Deputy Director of PEB, a 2015 Highly Cited researcher, and co-leads Research Program 1 with Ian Small.

PROFESSOR JUSTIN BOREVITZ

Justin's research applies cutting edge genomics and phenomics approaches to the study of the genetic basis of climate adaptation in plants, and utilises model plants and foundation species in controlled and field environments. Justin co-leads Research Program 3 with Ryan Lister.

PROFESSOR OWEN ATKIN

Owen's research focuses on assessing the impact of environmental gradients on plant physiological processes, particularly respiration.

PROFESSOR JIM WHELAN

Jim's research combines morphological, biochemical, genetic and 'omic' approaches to understand organelle function and biogenesis in plants. Jim co-leads Research Program 2 with Steve Tyerman.

ASSOCIATE PROFESSOR MATTHEW GILLIHAM

Matt's research focuses on the physiological role of solute transport proteins in plant nutrition and in conferring tolerance to various stresses such as salinity, drought and aluminium. He is an ARC Future Fellow.

PROFESSOR STEVE TYERMAN

Steve investigates the links between anion and water transport in plants and, as Wine Industry Chair of Viticulture at the University of Adelaide, he applies his research to grapevine root physiology. Steve is a Fellow of the Australian Academy of Science and co-leads Research Program 2 with Jim Whelan.

Our Partners

(GERMANY)
Max-Planck Institute for Molecular Plant Physiology

The MPI-MP is the elite European institute for research into central plant metabolic pathways, combined with analysis of gene function for development and implementation of phenotyping technologies and system approaches. Mark Stitt and Ralph Bock, two of MPI-MP's Directors, are partner investigators to PEB. MPI-MP has made a substantial commitment to collaborations within the Centre's programs, the provision of facilities for collaboration and to the support of PEB visitors.

(UNITED STATES OF AMERICA)
Salk Institute for Biological Studies

The Salk Institute focuses on discovery, and on mentoring future generations of researchers in genetics, cell and plant biology, and related disciplines. Two of its leading research professors, Joseph Ecker and Joanne Chory are partner investigators in PEB. Salk have made in-kind commitments to staff time for collaborations in all programs, to extensive access to facilities and new datasets for collaborations and to the support PEB visitors.

(SWEDEN)
Umeå Plant Science Centre

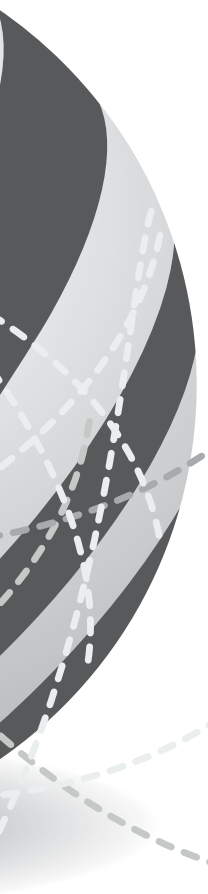
UPSC is one of the strongest research environments for basic plant research in Europe and covers a wide range of disciplines in plant biology. UPSC share a common goal to understand the mechanisms driving chloroplast biogenesis and plant adaptation to environments. Åsa Strand, from UPSC, is a partner investigator in PEB. UPSC will provide in-kind commitments in staff time for collaborations, and facilities for collaborations and PEB visits.

(FINLAND)
University of Turku

The University of Turku houses the Finnish Centre of Excellence in Molecular Biology of Primary Producers. Its Director, Eva-Mari Aro, is a partner investigator in PEB. The Centre will participate through research on chloroplast biogenesis and signalling, and chloroplast function. In-kind commitment will be provided in staff time and facilities for collaborations.

(UNITED STATES OF AMERICA)
University of Massachusetts

Umass (Amhurst) is a major US research and teaching university with a strong reputation in plant science innovation. The UMass team, led by Elizabeth Vierling, research temperature responses in plants and will collaborate with PEB to search for new gene networks for temperature tolerance in plants. Additional in-kind commitments will involve follow up work at UMass and the hosting of visiting PEB staff



(FRANCE)
Groupe Limagrain

Groupe Limagrain is an international agricultural cooperative group and the world's fourth-largest seed company. It will fund research on controlling male fertility through the manipulation of mitochondrial gene expression. Limagrain is providing wheat germplasm, testing candidate gene sequences proposed by the Centre, and evaluating lines for male fertility and the ability to produce hybrid wheat. Limagrain will provide plant biotechnology development and licensing expertise to PEB.

(CZECH REPUBLIC)
Photon System Instruments

PSI are a leading developer of new technology for imaging of plant growth and development. They will fund the development of instrumentation and new software for use in the Centre, and for deployment across Australia and will bring imaging expertise to a number of Centre's projects.

(AUSTRALIA)
Agilent Technologies

Agilent Technologies supports advances in life and agricultural sciences, and 'omic analysis and integration as an instrument manufacturer and product developer. The company will work closely with PEB on analytical workflow solutions, automation and robotics in quality control for plant-sample QC analysis, and on refining laboratory management software and analysis. Agilent Technologies will provide analytical product development expertise to PEB's Business Advisory Group.

(AUSTRALIA)
Grain Research and Development Corporation

The GRDC invests in crop science for the Australian grains sector. GRDC will provide PhD scholarships and research costs to PEB and fund projects arising from CIs' discoveries for improving salinity tolerance and drought tolerance in wheat and barley. The GRDC will give advice to the Centre, evaluate new PEB intellectual property for further funding by GRDC, and will provide knowledge and links for PEB to Australia's grains industry.

(CHINA)
Zhejiang University

ZJU is a major Chinese agricultural university and leads a large research program in increasing phosphate use efficiency in rice. ZJU's partnership role will be in the collaborative development of rice varieties, with emphasis on use of its extensive field sites to facilitate translation from PEB's discoveries.

Partner Highlight

Clarifying phosphate remobilisation mechanisms through collaboration

Significant storage of phosphate for plant growth can occur in leaf photosynthetic cells. Mechanisms by which this phosphate is remobilised when required were unknown, until recently. A collaborative investigation with our partner research group, led by Professor Huixia Shou, at Zhejiang University (ZJU) in China has helped to clarify how phosphate is remobilised with the discovery of a key phosphate transporter that regulates phosphate storage.

A PEB multi-node research team characterised a putative phosphate transporter from rice, OsSPX-MFS3. Studies in PEB's Whelan laboratory with Dr Secco and Prof. Shou identified OsSPX-MFS3 to be located on the vacuolar membrane. Genetic approaches suggested OsSPX-MFS3 works to drive phosphate out of the vacuole into the surrounding cytoplasm. Studies by PEB's Tyerman group, using sensitive electrophysiology on *Xenopus* oocytes expressing the protein, revealed the gradient in hydrogen ions across the membrane as the energy source driving the flow of phosphate.

Experiments at ZJU demonstrated that when OsSPX-MFS3 protein was over expressed in rice leaf cells the content of phosphate in the leaf vacuoles decreased markedly, indicating that phosphate was being exported from the leaf cell vacuoles.

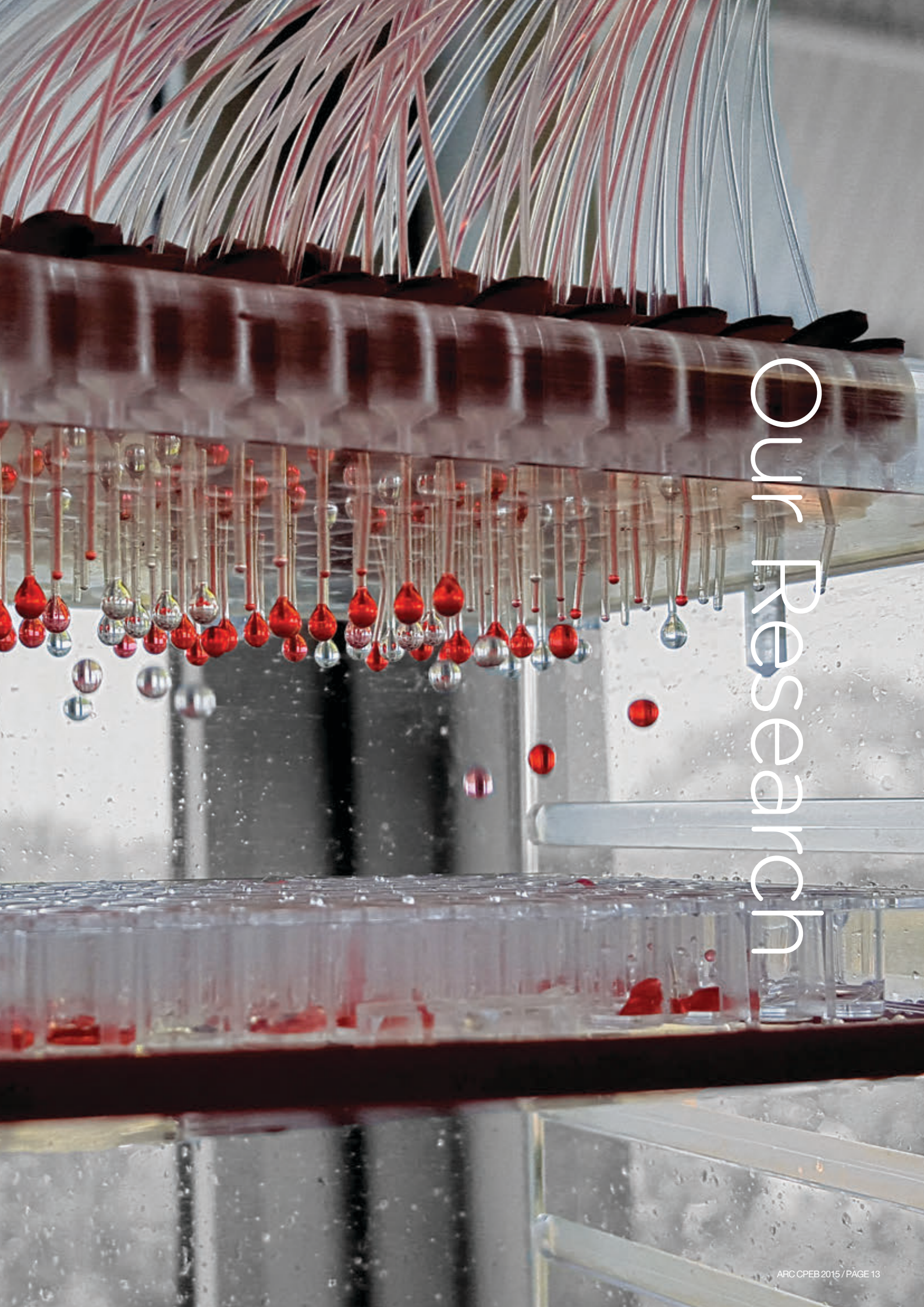
"Combining ZJU's expertise in genetics and transformation with our expertise in characterisation of transporter proteins has revealed a comprehensive picture of phosphate remobilisation in rice" said Prof. Tyerman.

This is the first report of a phosphate transporter in plants located on the vacuolar membrane and opens up possibilities for the engineering of more phosphate efficient plants.

Wang C, Yue W, Ying Y, Wang S, Secco D, Liu Y, Whelan J, Tyerman SD, Shou H (2015) Rice SPX-Major Facility Superfamily3, a vacuolar phosphate efflux transporter, is involved in maintaining phosphate homeostasis in rice. PLANT PHYSIOLOGY 169(4):2822-31.

The plant energy system is the largest set of biochemical reactions on earth.

The most pressing challenge for plant scientists is to understand the regulatory mechanisms that govern the efficiency of this energy system in order to modify it for gains in plant performance under changing environments.



Our Research

Our Research

What Is Plant Energy Biology?

Much of our food, feed, fibre and fuel is sourced directly or indirectly from plants in the form of energy-containing, nutrient-rich molecules. The synthesis, transport, storage and use of these molecules during plant growth and development is the *plant energy system.* The efficiency of a plant's energy system determines its final yield of plant products.

The efficiency of the plant energy system can be measured at different levels:

- In cells, as the proportion of energy used for cell maintenance versus growth.
- In whole plants, as the ratio of input resources versus harvestable product.
- In the environment, as the degree of adaptation within plant populations needed to grow successfully in variable conditions.

These measures serve as proxies for plant energy efficiency, an incredibly complex but essential plant trait.

The world urgently requires plants that can more efficiently attain the resources provided by nature and by farmers and generate more harvestable products. Furthermore it needs plants that can to do so on agricultural soils that are decreasing in area and fertility, and that can maintain their performance in harsh and variable environments.

Energy efficiency, which sits at the centre of this requirement, can be gained or lost at multiple levels:

- At the molecular level, in the control of gene expression and metabolic processes.
- At the cellular level, through specialisation and signalling.
- At the developmental level, through physiological responses to the environment.

These gains and losses cumulatively impact across spatial scales, from tissues, to whole plants to plant populations.

The Problem

Presently, even under ideal conditions, elite crops only convert 10–15% of the carbon fixed by photosynthesis into harvestable yield, with even less efficiency seen under harsh environments. Under suboptimal environments and in certain seasons, crop yields well below potential maxima are observed. In Australia, 60% yield gaps between potential and actual yield are now common.

Yields have varied more greatly since 2000 than in any period since 1950. Droughts of moderate severity lead to a 30–70% yield decrease. The impact of saline soils and temperature extremes ranges from small losses up to complete crop failure, and nutrient-limitation can lead to an 80% decrease in yield.

The Solution

Many of these partial losses occur due to limitations and reduced efficiency in interconnected metabolic processes. Thus, small efficiency gains in the multitude of processes beyond carbon capture, but before harvest, can combine to have a magnified benefit on yield.

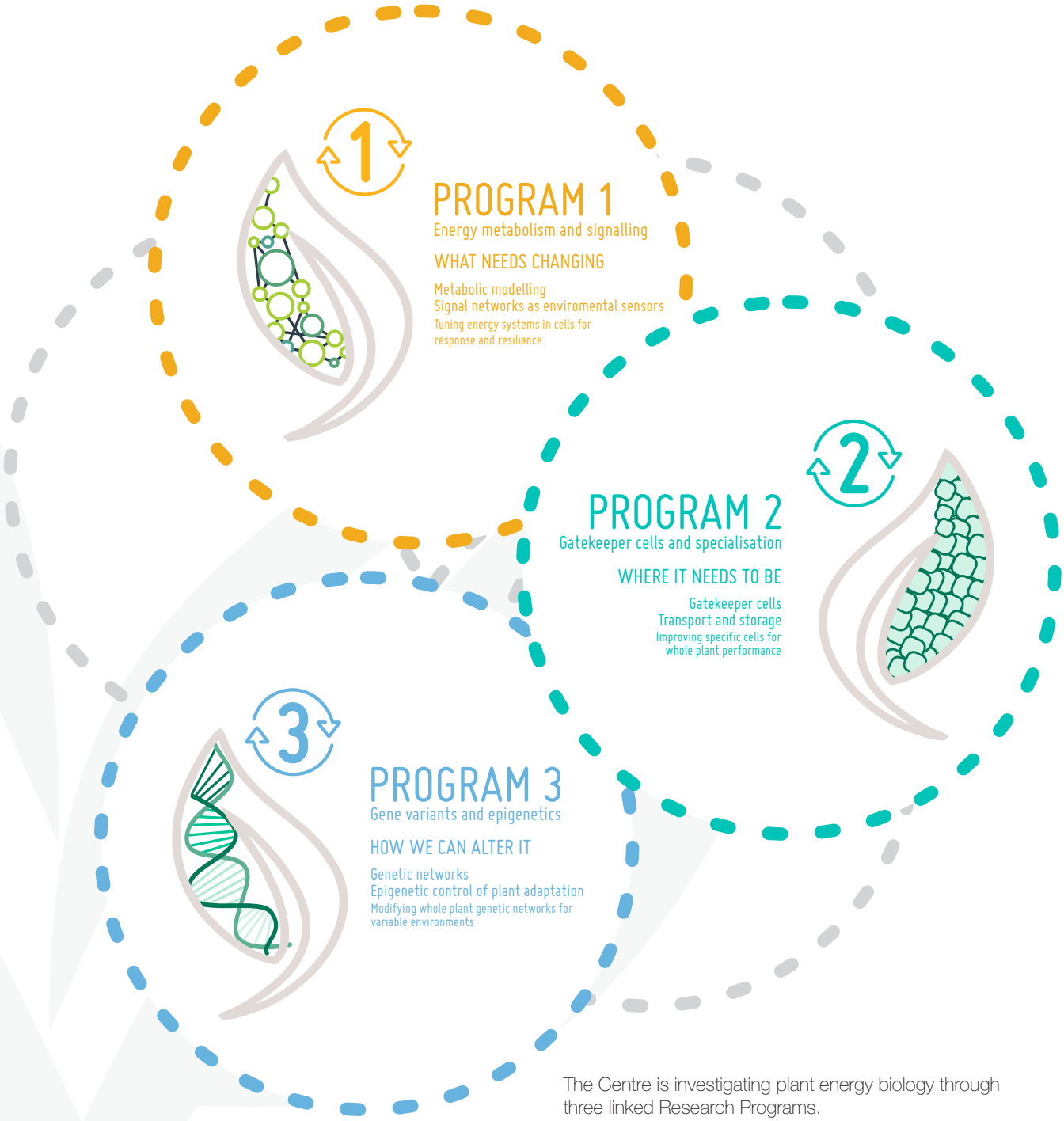
Discovering the interconnected signalling processes that dictate and limit how plants perform in variable environments is critical to gaining the sustainable increases in actual plant yields that are needed for our future.

Major targets for efficiency gains include the energy spent on: translocation of carbohydrates and nutrients from leaves to roots and seeds; uptake and storage of nutrients from soils; assimilation and allocation of phosphate, nitrogen and sulphur into proteins, lipids and organics; protein synthesis and turnover and maintenance of cellular ion-gradients.

Tackling plant energy research requires a team with expertise ranging from genes and proteins through to plant physiology.

Through our combined expertise and using technological innovation the Centre can enhance the energy efficiency of plants.

We are focused on understanding plant energy biology and using this knowledge for application and impact, both within and outside the bounds of plant science.



The Centre is investigating plant energy biology through three linked Research Programs.

Program 1 will define what elements in energy metabolism are the best targets for increasing energy capture and conversion in specific conditions.

Program 2 will define where energy use for resource acquisition in specific cells can have a maximal benefit for the whole plant.

Program 3 will define how networks of genes governing these processes can be identified and manipulated in plant populations for robust responses in limiting environments.

Program 1 Energy Metabolism and Signalling

Program leaders: Ian Small and Barry Pogson
Program 1 focuses on cellular functions.

Background

The chloroplast/plastid and the mitochondrion are the two major organelles in plant cells. These organelles co-operate to direct plant cell energy capture and storage of this energy in the form of sugars, starch, oils, protein and fibre - all of which are major agricultural products.

The metabolism of plant organelles underlies the growth and performance of a plant, including its ability to withstand environmental stresses. The Centre has previously shown that chloroplasts and mitochondria are environmental sensors that control growth. Environmental variables such as light, temperature, water and nutrient availability all interact with plant energy systems via signalling processes.

The complex and ancient ways in which organelle function and efficiency are influenced and respond to the environment form the foundation of how plants control conversion of energy to functionally useful forms.

Program Aim

Maximise the efficiency of energy organelles by modelling the efficiency of metabolic strategies in plants, altering the biogenesis of energy organelles and co-opting the signalling processes that control the activity of energy organelles during environmental challenges and recovery.

- **Modelling energy processes under varied conditions to choose optimal energy efficiency strategies.**
  Good estimates of energy capture and expenditure at a whole plant or organ level can be made from measurements of photosynthetic and respiratory rates. However, sufficiently detailed information about the energy requirements of internal processes does not yet exist to guide the development of optimal strategies that improve energy efficiency under target conditions.

  The Centre's previous developments in metabolic modelling, organelle composition and protein turnover analysis provide a technical foundation on which to investigate the energy requirements of internal processes.

- **Modifying energy organelle number, quality and function to improve energy processes in variable environments.**
  The Centre has defined 'switches' that control energy organelle biogenesis and function in the processes of respiration and photosynthesis. PEB is now utilising these to change metabolic outcomes in plant cells, through collaborative research with our partners.

  Combined with a number of established resources, including plant lines with altered organelle biogenesis and growth characteristics, this provides novel opportunities to measure and modify cellular costs and identify new signals of interest.

- **Using the receptors and transducers of organelle signals to integrate changes across whole plants.**
  PEB has identified key signals that build a strong case for the existence of overlapping cell signalling pathways which contribute to environmental sensing by organelles. The Centre is now undertaking research to address whether organelle number or composition can be optimised by regulating signalling networks and whether this can, in turn, optimise plant performance.

  PEB researchers are investigating networks to define what evolutionary boundaries can be jumped and which networks can be rewired without compromising other aspects of energy efficiency.

Regulators of energy efficiency are not directly selected for by most current breeding strategies, meaning there is considerable potential for improvement. Future assisted breeding of crops requires knowledge of networks of molecular targets that are yet to be discovered. PEB's research will aid in identifying such targets and lead to enhanced plant energy efficiency for yield by focusing on improvements that can be stacked together for gains in crops.

Personal Success

Originally from France, ***Dr Bernard Gutmann*** joined PEB in 2013 bringing with him a highly prestigious European Molecular Biology Organization (EMBO) Long-Term Fellowship to study the potential of pentatricopeptide repeat (PPR) proteins for biotechnological applications. His work has improved the analysis and characterisation of the distinguishing features of PPR motifs, identifying a new PPR subgroup in the process.

In 2015 Bernard secured a Discovery Early Career Research Award and begun applying his knowledge to the design of synthetic PPR proteins.

"Creating a new biological tool is like cooking" he said. *"After a few years you master the different cooking techniques and flavours. And then it's your turn to create something new".*

Bernard enjoys combining new things to obtain results that can benefit the world. He also relishes collaborating within his team and with others.

"In France, a saying goes that behind every great man there is a great woman. For a scientist it is the same, behind each scientist there is a great team".

Personal Success

While new to PEB in 2015 ***Dr Brendan O'Leary*** has been a part of teams at two of PEB's Australian nodes. Brendan joined the Atkin group at the Centre's ANU node in early 2015, before joining PEB UWA as a new Discovery Early Career Research Award Fellow later in the year. Brendan brings to the Centre his expertise in plant metabolism.

"I was drawn to PEB by the quality and reputation of the principal investigators as well as the level of support available within the Centre" he said.

One of his projects bridges between ANU and UWA and between the fields of physiology and biochemistry. The project looks at variation in plant respiration within a species, linking physiology of respiration expertise in the Aktin lab with expertise in the Millar lab in the biochemistry of respiration.

A significant outcome for Brendan and the Centre in 2015 was the novel adaptation of a new technology to perform high throughput respiration measurements from plant leaves.

"The successful use of the Q2 robotic oxygen sensor for high-throughput leaf respiration measurements means that many questions surrounding plant respiration that were not experimentally tractable before can now be addressed."

Research Highlight

Towards synthetic RNA processing tools

The ability to design proteins capable of executing specific, desired tasks within a cell is the long-held dream promised by synthetic biology. However, few proteins are sufficiently well understood to make such a redesign possible. The Centre is developing such technologies for targeted alteration of RNA sequences, for future applications in agricultural and medical biotechnology.

An important step towards this goal was taken last year with the publication of a set of experiments demonstrating that an RNA editing factor (CHLOROPLAST BIOGENESIS 19, or CLB19) could be easily altered to change its RNA binding preferences.

CLB19 is a pentatricopeptide repeat (PPR) protein, one of a family of hundreds of similar proteins that specify the sites at which plastid and mitochondrial transcripts are 'edited' through nucleotide deamination. Previous work performed in the Centre elucidated how PPR proteins recognise their target RNAs.

The latest research extends that work to show how our understanding of the recognition code can be used to divert CLB19 preferentially towards one or other of its two target RNAs. The same approach was shown to work equally well with a second PPR editing factor.

These are the first *in vivo* demonstrations that the RNA binding specificity of PPR proteins can be engineered, and will drive further research into the design and testing of RNA processing tools based on natural and synthetic PPR proteins. An early target for this research will be the control of plant fertility through suppression of cytoplasmic male sterility, enabling more widespread use of F1 hybrids in agriculture.

Kindgren P, Yap A, Bond CS, Small I (2015) Predictable alteration of sequence recognition by RNA editing factors from *Arabidopsis*. PLANT CELL 27(2) 403-16.

Research Highlight

A not-so-futile signalling pathway

Mitochondria provide the energy to drive growth and maintenance and to combat stresses in all organisms, including plants. It is known, however, that plant mitochondria contain a "futile" pathway for respiration, one where sugar is respired but no energy is produced, only heat.

This occurs in addition to an energy producing / conserving pathway. Studies suggest that the enzyme that catalyses the futile, alternative pathway - the alternative oxidase - plays a role in defence response. However, until recently, it had remained unclear if the alternative pathway promotes or retards plant growth.

Using genetic approaches a team at the Centre set out to address what the influence of the mitochondrial alternative pathway is on plant growth. The alternative pathway, the energy producing/conserving pathway or both were partially abolished in plant cells.

The results of this revealed that when the energy producing/conserving pathway is blocked, the alternative pathway supports growth. Furthermore, if both pathways are blocked the plant suffers far more than if the energy producing/conserving pathway alone is blocked.

These results suggest a crucial role for the alternative pathway in supporting the growth of plants. The findings highlight the dynamic signalling responses in plants to the perturbation of mitochondrial function caused by different growth conditions, and have important implications for energy budgets in plant cells.

Kühn K, Yin G, Duncan O, Law SR, Kubiszewski-Jakubiak S, Kaur P, Meyer E, Wang Y, Small CC, Giraud E, Narsai R, Whelan J (2015) Decreasing electron flux through the cytochrome and/or alternative respiratory pathways triggers common and distinct cellular responses dependent on growth conditions. PLANT PHYSIOLOGY 167(1):228-50.

Program 2 Gatekeeper Cells and Specialisation

Program Leaders: Steve Tyerman and Jim Whelan
Program 2 focuses on cell types and their interactions in plants.

Background

Australia is the most saline continent on Earth. Approximately 69% of the Australian wheat belt is susceptible to the build-up of salts, which are inhibitory to plant growth. The extent of worldwide salinity is forecast to increase in the coming decades due to climate change and a greater reliance on marginal land. Meanwhile, phosphate global supplies are running out, yet this is an essential macronutrient for plants that can severely limit growth and yield unless supplied as a fertilizer.

Acquisition of necessary nutrients, control of resource transport and the exclusion and cellular detoxification of toxic substances are energy intensive for plants. To secure our future we require plants which are more efficient at these processes. Key cell-types often form rate-limiting steps within the transport pathway of nutrients, metabolites and toxins in plant. We call these strategically located cells "gatekeepers".

Program Aim

Improve the efficiency of plant energy use during the acquisition and partitioning of key resources by manipulating the transport properties of gatekeeper cells for water, carboxylates, phosphate, and salt. Single-cell analysis and modification will be used to harness the profound impact these cells have on whole plant energy efficiency in response to deficit or oversupply of nutrients, metabolites and toxins..

- **Optimising energy use in resource acquisition processes.**
  Water and fixed carbon, as resources, are intimately linked to plant energy status. The Centre's research into water and carboxylate transport is exploring the inter-relationship of this with metabolism in specialised gatekeeper cells. The control of genes that code for water and carboxylate transport proteins are the new frontier for nutrient acquisition gains. These transport proteins are highly regulated and linked to the energy status of cells, as well as to stresses such as salinity and extreme pH. Reasons for these links are not understood, and the Centre is exploring them as an untapped resource for plant improvement.

- **Maintaining cellular energetics optimised under saline conditions through exclusion and tissue tolerance.**
  Soil salinity reduces the energy efficiency of cellular processes, including lowering photosynthesis and raising respiration, resulting in reduced crop yield.

  The Centre has previously demonstrated how a single gene can confer improved salt tolerance in wheat without penalty to yield, when expressed in specific gatekeeper cells.

  PEB are now discovering parallel pathways to further optimise crop productivity within saline environments through specialised cell types. This work is enhanced by the Centre's access to unique Australian cereal genotypes and the mapping of populations differing in key traits that underpin salinity tolerance.

- **Altering phosphate uptake, storage and use as keys to the energy currency of cells.**
  Phosphate is needed in plant energy metabolism as a component of high-energy molecules. The Centre, however, aims to design proof-of-concept plants that maintain biomass and yield under low phosphate conditions.

  Approaches combine cell specific targets for compounds involved in phosphate status signalling, regulators of the proteins that control phosphate homeostasis, and the regulatory genes for phosphate starvation identified through genome and epigenome analysis. This multi-faceted approach aims to avoid the trade-offs in phosphate responses that impact plant growth.

Program 2 will link to Program 1 through the use of cell specific energy flux measurements, and through the assessment of organelle enhanced plants on nutrient acquisition and toxin tolerance. Findings will inform the generation of crops better suited to a changing agricultural landscape.

Personal Success

2015 was a very successful year for postdoctoral researcher, ***Dr Stefanie Wege.*** She was awarded the Edith Emily Dornwell Early Career Research Medal by the University of Adelaide in recognition of early career research excellence. She was also successful in her application for a Discovery Early Career Research Award, which will commence in 2016.

Stefanie studies nutrient transport in plants. Her PhD project had her study a protein family capable of transporting both nitrate and chloride and she has been fascinated by how these two nutrients are interconnected within the plant system ever since.

"I think there is so little known about what chloride does in plants" she said. *"There is still so much to discover and understand. I hope with better understanding and managing of chloride in plants we will be able to reduce nitrate fertiliser usage while maintaining crop yield".*

Stefanie enjoys researching as part of REB. Originally from Germany she said "attending PEB's annual meetings gives me a fantastic opportunity to get to know different researchers from all over Australia, something that is especially important to me having come from overseas".

"PEB is really helping me to build a new network of collaborators here in Australia".

Personal Success

Dr Megan Shelden became a valuable addition to the PEB team in 2015 bringing with her Discovery Early Career Research Award funding and expertise in root biology, plant biochemistry and functional genomics. Her research focus is in the area of tolerance to abiotic stress, specifically salinity and drought, in agricultural crops.

The ability of the root system to adapt to abiotic stress and maintain growth by increasing root soil exploration for nutrient and water uptake is of particular interest to her.

In 2015 Megan was awarded a Premier's Research and Industry Fund's Catalyst Research Grant by the South Australian Government. The funds are being put towards her research project *Screening for salt-tolerance in wheat using impedance spectroscopy: a novel technique to reveal performance in the hidden half.*

"We are using an innovative technique called electrical impedance spectroscopy to measure root growth of plants within the soil, without having to destroy the plants" she said. *"We hope the technology will lead to an inexpensive and rapid screening method for measuring root growth in cereal crops that could be potentially adapted to other agriculture crops."*

Megan is excited by the opportunity to direct her own research and build a research team. *"I am very happy to be part of PEB and work in an innovative and supportive environment with a dynamic group of scientists!"*

Research Highlight

Molecular mechanisms for surviving salinity

Plant salinity stress is a problem in grape growing regions that rely on irrigation water from increasingly salty sources. Researchers at the Centre have been investigating grapevine gene function with the aim of improving grapevine performance in saline environments.

Cation-chloride cotransporters (CCC) are membrane proteins that transport chloride ions, together with sodium and/or potassium, across cellular membranes. CCC have been well studied in animals. Their role in plant ion homeostasis is less well understood.

Centre researchers investigated the function of the grapevine CCC to determine its role in plant salt tolerance. A mutant of the model plant species *Arabidopsis thaliana* lacking a functional CCC gene had stunted growth and over-accumulation of sodium and chloride in leaves. When the grapevine CCC was expressed in this mutant plant normal growth and normal sodium and chloride levels were restored.

PEB researchers are continuing to investigate how the activity of plant CCC proteins is regulated in response to environmental change, to further characterise their role in grapevine salt tolerance.

Henderson SW, Wege S, Qiu J, Blackmore DH, Walker AR, Tyerman SD, Walker RR, Gilliham M (2015) Grapevine and *Arabidopsis* cation-chloride cotransporters localise to the Golgi and trans-Golgi network and indirectly influence long-distance ion homeostasis and salt tolerance. PLANT PHYSIOLOGY 169: 2215-2229

Research Highlight

Understanding how plants cope with stress

Plants are sessile and thus their survival depends on their ability to perceive environmental cues and respond appropriately. Under both abiotic and biotic stresses plants rapidly accumulate y-aminobutyric acid (GABA), which modifies plant growth. While GABA is a well-known neurotransmitter signal in animals - working through GABA receptors - its role in plants as a signal has only been hypothesised, with experimental evidence for a 'plant GABA receptor' lacking.

Centre researchers, examining the effect of combined abiotic stresses on the modulation of plant growth, discovered that GABA could regulate the activity of ion channels from the Aluminium Activated Malate Transporter (ALMT) family.

Further experiments found that ALMTs could transduce GABA signalling in plants leading to altered plant growth. These 'plant GABA receptors' are quite distinct from their animal counterparts except in a small 12 amino acid region that shares significant homology to a GABA binding site in mammalian $GABA_A$ receptors.

Sunita Ramesh, co-first author on the *Nature Communications* publication of this work describes the paper as "the exciting culmination of almost three years of research, and of collaborations with many scientists from Australia and abroad". Centre researchers are now investigating whether this discovery can be exploited in the development of more stress resilient crops

Ramesh SA, Tyerman SD, Xu B, Bose J, Kaur S, Conn V, Domingos P, Ullah S, Wege S, Shabala S, Feijé; JA, Ryan PR, Gilliham M (2015) GABA signalling modulates plant growth by directly regulating the activity of plant-specific anion transporters. NATURE COMMUNICATIONS 6:7879.

Program 3 Gene Variants and Epigenetics

Program Leaders: Ryan Lister and Justin Borevitz
Program 3 will focus on plants in populations and across generations.

Background

Across diverse habitats plant populations fine-tune their energy systems to withstand and exploit changing environmental conditions. Natural genetic diversity contains many useful traits, the molecular basis of which can now be mined from plant genomes by unifying modern genomics technologies with precision phenotyping and sensitive environmental observation, at both the individual and population levels.

In addition to determining the genetic complement of an organism, it is critical to understand the epigenetic codes that govern where and when the genetic information is used. Epigenetic modifications do not alter the genome sequence, but can regulate the readout of the underlying genetic information, can be environmentally sensitive and heritable.

Project Aim

Identify genetic and epigenetic control of energy efficiency during plant growth by dissecting out how this couples with phenomic variation in natural populations of plants using genome wide association mapping, and through (epi)genome profiling in a variety of environments.

- **Exploiting (epi)genetic variation to define the gene networks and gene variants that determine energy efficiency.**
  The historical selection of plants for their growth in less challenging environments than today has resulted in bred plants that do not possess the resilience found in natural populations due to their largely untapped bank of (epi)genetic solutions to challenging environments.

  The Centre is driving major advances in tools to precisely dissect out these (epi)genetic solutions from natural populations of plants.

  This will clarify the contribution of the (epi)genome to natural variation in plant energy systems and the molecular basis of how plants transform energy to grow and survive in changing and challenging environments.

- **Uncovering the role of epigenetics through multigenerational responses to environments.**
  It has recently been proposed that epigenetic modifications in plant genomes can change rapidly, in an apparently stochastic manner, and may transmit to subsequent generations of plants. There is also mounting evidence that the plant epigenome undergoes specific changes in response to challenging environmental conditions.

  It is critical to understand the role of epigenetic plasticity in plant multigenerational responses to challenging environments.

  Understanding how multigenerational epigenomic variability influences genetic and phenotypic variation under challenging conditions will allow control of the process to generate stable and resilient plants in the future..

- **Developing new tools for precision editing of the epigenome to engineer plant energy efficiency.**
  To further study and manipulate genes and cellular signalling pathways the Centre aims to specifically transfer (epi)alleles across plants. Through novel approaches to precision editing of epigenetic patterns, such powerful genome editing technologies will allow the transfer of advantageous genetic variants.

  By further modification of new genome editing systems we will develop innovative targeted epigenome engineering tools to deliberately reprogram the epigenome.

We will target dynamic plant responses to changing environments and conditions, with specific focus on light, drought, temperature extremes and nutrient-limitation. Our approaches will enable the design, breeding or selection of plants that achieve significantly higher efficiency under limiting conditions and when conditions change in the future.

Personal Success

Shortly after joining PEB's Lister group, ***Dr Aimone Porri*** was awarded a prestigious European Molecular Biology Organization (EMBO) Fellowship which commenced in 2015.

Aimone's research interests lie in the application of genome-editing technologies to confer favourable characteristics to crops. He aims to develop new molecular tools that allow the deliberate and precise induction of changes in DNA methylation and chromatin state to the genome of the model plant *Arabidopsis thaliana.*

"I grew up on a farm in Tuscany and have always been fascinated with plants and agriculture" he said. "It was a dream to become a plant scientist - being surrounded by plants brings me back to my childhood".

His research will explore the use of innovative epigenome engineering tools which he hopes will have widespread applications in agriculture and biomedicine.

Personal Success

As a new Discovery Early Career Research Award Fellow in 2015 ***Dr Steve Eichten*** has been studying genomic and epigenomic relationships with adaptive plant phenotypes as part of the Borevitz group.

"Biology was always interesting to me," he said *"and plants were always a nice system to work with. Their importance cannot be overstated".*

Steven is studying chromatin variation and transposable element variation within the model cereal *Brachypodium distachyon* to determine how these sources of possibly rapid adaption within populations may be tied to environmentally adaptive phenotypes.

"Adaptation to environmental change is required for species to persist. However rapid environmental change may exceed the limits of traditional genetic adaptation leading to widespread species decline" said Steven. He hopes his work will identify sources of rapid adaptation allowing plants to address these environmental challenges.

"Working with PEB has allowed me to interact with a great group of plant scientists and has led to many unique collaborations."

Research Highlight

The art of surveying plant populations for adaptive genetic diversity

This overview study outlines years of experimental design experience to guide new practitioners in the art of surveying natural populations for adaptive genetic diversity.

Two components are detailed. The first is to survey for breadth across the species range to understand background genetic patterns of population structure. High throughput, reduced representation (de novo) Genotyping. By Sequencing is suitable here to identify outlier populations, hybrid zones and centres of diversity, which can be prioritised for conservation and resampling.

The second part is to dissect out the adaptive genomic regions from neutral background variation via mixed model association studies. Here, whole genome (re)sequencing of targeted admixed samples spanning a sharp ecological or environmental cline is used to build the dataset.

With this knowledge, landscape restoration practitioners can select the most suitable adaptive genotypes for current and future environments while maintaining diversity for unknown challenges and avoiding genetic bottlenecks.

Bragg JG, Supple MA, Andrew RL, Borevitz JO (2015) Genomic variation across landscapes: insights and applications. NEW PHYTOLOGIST 207: 953–967.

Research Highlight

Stress induced silencing of "parasitic" DNA

Modern agriculture's heavy reliance on phosphate rich fertilisers is unsustainable. Thus, there is an urgent need to understand how crops are affected in times of phosphate shortage. This study investigated changes in cytosine DNA methylation in both rice and *Arabidopsis* plants when deprived of phosphate. In rice plants the pattern of DNA methylation changed., and this was particularly evident near specific genes that help the plants survive under difficult conditions.

Notably, in the absence of phosphate, DNA methylation also occurred more often in "parasitic" transposable elements that sit close to these useful genes, and less often around other genes.

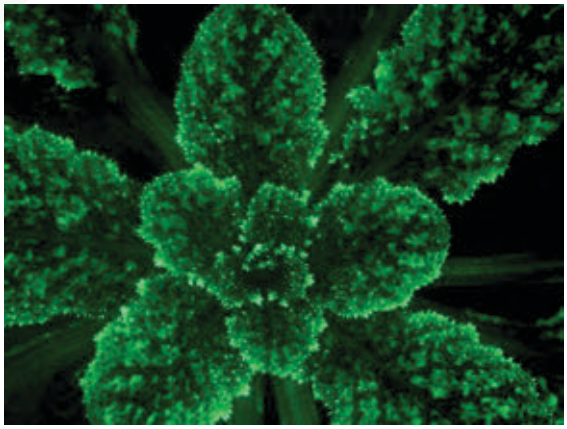
Thus, the extra methylation observed in these regions may be a defense measure taken by the plant in order to inactivate transposable elements and limit the potential deleterious effects of their activation and movement in the genome.

Further experiments showed that useful genes appear to be switched on before the DNA of transposable elements is methylated, implying that the extra methylation observed in transposable elements is a consequence of the activation of nearby, useful genes.

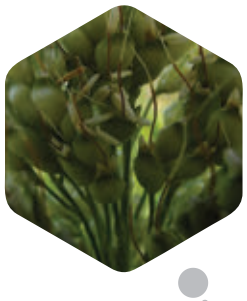
In contrast, similar experiments performed in *Arabidopsis* revealed very limited change in DNA methylation when the plants were grown under stressful conditions.

The next challenge will be to explore how significant the environmentally induced silencing of transposable elements is to the stress responses and genome integrity of crop plants.

Secco D, Wang C, Shou H, Schultz MD, Chiarenza S, Nussaume L, Ecker JR, Whelan J, Lister R (2015) Stress induced gene expression drives transient DNA methylation changes at adjacent repetitive elements. eLIFE.



Translation of Research to Application



TOOLS FOR HYBRID CROP BREEDING

The use of hybrid crop varieties is increasing because of their attractive agronomic traits. Development of hybrid breeding systems requires a means to control self-pollination. Cytoplasmic male sterility (CMS) and fertility restoration is one approach that has been exploited, but the lack of suitable restorer genes has been a major limiting factor. Work by the Centre has identified PPRs as the major group of *restorer of fertility* (Rf) genes in plants and is developing approaches to find effective natural variants and to design synthetic ones.

By identifying Rf genes in genomic data from cereals (including wheat and sorghum) the Centre is helping its partners to use this approach to restore male fertility. Our partners, including Limagrain, University of Queensland and the U.S. Department of Agriculture, will test candidates in field trials. We believe this approach will be valuable to plant breeding companies keen to develop new hybrid varieties, particularly in crops where such hybrids have been difficult to create.

RELEVANT MODELLING OF CLIMATE

The Centre is working at the frontline of plant research that utilises systems to model dynamic climatic conditions in physiologically and ecologically relevant ways. The research team has developed pipelines that enable high throughput studies under dynamic environmental conditions using growth chamber technology.

Spectral climate chamber facilities enable the fine control of light intensity and spectrum, temperature and moisture to simulate local and regional field-like conditions from particular locations and seasons. Refining the use of such systems equips the Centre with the means to perform future work in climate analogues that mimic specific growth regions or climate change scenarios, greatly enhancing translation of the Centre's discoveries to real-world application. These systems are being developed by the Centre not only for important model research plants such as *Arabidopsis* and *Brachypodium* but for crop plants, such as wheat.

MAPPING HUMAN EPIGENOMES

Technologies developed in plant models can be applied to other organisms. The application of the Centre's advances in epigenome analysis has not been limited to plant and agricultural research.

Collaboration with the Salk Institute for Biological Studies has demonstrated that epigenetic mapping technologies and the study of de novo methylation patterns in plants can also be applied to the generation of complete epigenome maps and a better understanding of methylation patterns in the cells of humans and other organisms. Unlocking the secrets of plant biology may have far reaching benefits that can to translated to other fields of research, including human development and health and to the understanding of other living things.

TARGETED PROTEOMICS FOR CROP RESEARCH

Research in wheat at the protein level has been restricted by the limited availability of suitable antibodies and a lack of genomic data. A new method to accurately quantify proteins in many different tissues of wheat using a targeted strategy has been established by a team of PEB researchers. The SRM mass spectrometry, or "targeted proteomics " approach dispenses with animal-produced antibodies for protein quantitation, and instead makes use of a triple quadrupole mass spectrometer and newly available genome sequences for wheat.

Targeted proteomics has the power to rapidly accelerate evaluation of both genetically engineered and naturally bred variants of important crop plants. A toolkit for other researchers wishing to utilise targeted proteomics has been developed by the Centre. PEB are now focusing efforts on establishing this approach in wheat to assess energy biology traits. Its application to wheat will form a part of the Centre's International Wheat Yield Partnership (IWYP) funded-project *Improving Wheat Yield by Optimizing Energy Use Efficiency*, which was announced in 2015.

BUILDING SALT TOLERANT CROPS

Many commercial crops are sensitive to soil salinity, causing major yield losses every year. The Centre has led a number of studies aimed at increasing salinity tolerance in crop plants important to the Australian economy including wheat, barley and soybean.

GmSALT3 was identified by Centre researchers as a gene conferring salt tolerance to soybean plants and this information can now be used in breeding programs to ensure that tolerance is maintained in future cultivars of soybean that will be grown in areas prone to soil salinity. Furthermore, the novel way in which this gene was found to confer salt tolerance is driving the search for similar genes in different crops such as wheat and grapevine to selectively breed for their own enhanced salt tolerance.

IMPROVING GRAPEVINE PERFORMANCE

The wine industry is a significant contributor to the Australian economy. Performance of grapevines is, however, being hindered by numerous factors, including increased soil salinity and variability in reproductive capacity. PEB researchers are tackling improving grapevine performance through a number of avenues of research. The Centre has identified molecular mechanisms that confer salt tolerance in grapevines which can assist with future breeding for more salt tolerant grapevine cultivars. Furthermore, the mode and timing of irrigation has been shown to effect salt accumulation in grape juice and wine through research conducted in the Centre.

This finding has received broad interest from growers. Other studies being contributed to by PEB researchers have dissected out an association between amines and the reproductive performance of grapevines, opening up opportunities for the modification of amine profiles as a tool to alter reproductive performance of grapevines. Meanwhile, a technique developed in the Centre for assessing berry quality using impedance spectroscopy is being considered for commercialisation.

New Research Technology & Resources

Our ability to answer scientific questions can be expanded with innovative technologies and resource. PEB research has given rise to a number of these that can enhance the breadth and the outcomes of research not only for the Centre but for scientists around the globe.

One-stop-shop for valuable crop data

cropPAL: Crop Proteins with Annotated Locations

The compendium of crop Proteins with Annotated Locations (cropPAL) was launched by the Centre in 2015.

Barley, wheat, rice and maize provide the bulk of human nutrition and have extensive industrial use as agricultural products. Each of the genomes of these crop plants contain more than 40,000 genes, each in turn encoding proteins. However, the major genome databases for these species lack annotation information about the subcellular location of greater than 80% of these proteins.

To address this gap PEB created a compendium of crop protein subcellular locations called cropPAL; *crop Proteins with Annotated Locations.*

CropPAL collates more than 550 data sets from previously published fluorescent tagging or mass spectrometry studies around the world, and ten pre-computed subcellular predictions for barley, wheat, rice and maize proteomes.

The data collection, including metadata for proteins, has been made publically available and studies can be interrogated through a search portal (www.crop-pal.org).

Protein subcellular location is an important clue to protein function, and to how proteins interact within the metabolic household. The subcellular localisation information housed in cropPAL helps to depict plant cells as compartmentalised protein networks that can be investigated for improving crop yield and quality and for developing new biotechnological solutions to agricultural challenges.

As an open access research tool cropPAL is a valuable asset to assist plant researchers, biotechnology companies and the crop breeding industry.

CropPAL was developed with the support of the Australian National Data Service (ANDS). Future plans are to expand the crop collection to include seven additional crop species, including grape, sorghum and canola.

Visualising data in virtual ways

EcoVR: The Virtual Reality Ecosystem Data Viewer

High density and high complexity datasets are of crucial importance for improving our understanding of ecology, climate change and for parameterising global climate models. New technology has provided ecologists with a wealth of data sources at spatial and temporal resolutions that were previously unimaginable.

However, our ability to collect data has rapidly overtaken our ability to work with, analyse and visualise these complex data in meaningful ways.

Meanwhile, the entertainment industry has spent billions of dollars developing tools for modelling the world in very high resolution, and affordable consumer devices for viewing such models have hit the market.

Recognising the potential to develop novel ways to organise and visualise new and exponentially more complex data types, the Centre is pioneering using Virtual Reality and Gaming Engines to build immersive replicas of ecosystems. In these environments physical objects in the landscape carry their own data streams that can be viewed by researchers on demand.

In early 2015, PEB researchers, together with students from ANU Computer Science Department's TechLauncher program, began EcoVR. This was a project to build an interactive model of the National Arboretum in Canberra, Australia, where time-series environmental data is overlaid on a spatially accurate 3D model of the ANU research forest.

The EcoVR software is a proof-of-concept application to explore novel solutions for visualising complex time-series environmental data overlayed on a landscape using a gaming engine and virtual reality headset.

EcoVR merges data from new monitoring tools including: microclimate mesh sensor networks, drones, NextGen LiDAR and gigapixel imaging, with virtual reality technologies to provide an exciting and versatile research tool to interrogate complex data for plant and related research.

This year, the Centre is again working with a team of students from the TechLauncher 2016 program to release a stand-alone software tool for public download and to expand the functionality of the software to provide a generalised tool for viewing geo-located time-series data in a 3D environment and with virtual reality.

Re-purposing an existing technology

Leaf respiration measurements using Q2 Technology

Astec Global's Q2 Technology was created for the high-throughput measurement of oxygen consumption by single seeds. The technology works by measuring fluorescence that is proportional to the oxygen concentration in a hermetically sealed sample tube. The instrument's ability to record oxygen levels over time can offer the oxygen depletion rate caused by seed respiration, and the unit's design allows measurements to be made at four different temperatures simultaneously.

Centre researchers interested in increasing their capacity to perform leaf respiration measurements en masse recognised the potential in this piece of technology.

These researchers have re-purposed the Q2 Technology for taking oxygen readings from leaf and other plant tissues.

PEB researchers have successfully optimised a protocol for leaf tissue measurements, taking into consideration variables such as tissue handling and preparation, optimal sample amount and appropriate instrument settings. Recent and continuing development of light sources to illuminate leaf tissue during Q2 measurements is occurring in-house, and by the manufacturer Astec Global.

Illuminating leaf tissue allows for oxygen evolution through photosynthesis to be measured. Hence, this technology can provide high-throughput screening of both respiration and photosynthesis.

The re-purposed Q2 Technology has proven valuable for a number of the Centre's studies, allowing high-throughput screening of leaf, root and stem tissues at varying temperatures, dramatically increasing the scope of numerous research projects at PEB's UWA and ANU nodes. One of the Centre's Q2 instruments was shipped to Mexico in 2015 as part of the Centre's International Wheat Yield Partnership (IWYP) funded-project *Improving Wheat Yield by Optimizing Energy Use Efficiency.*

At the IWYP field site, leaf respiration of 300 wheat genotypes, followed by a further 50 fully replicated genotype subsets, where surveyed using the Q2 instrument.

The Centre is now in possession of three Q2 instruments and PEB researchers plan to make available their methodology so that other plant researchers can take advantage of this high-throughput research approach. The Centre will also look to establish collaborative projects with outside researchers interested in using the technology.

Such collaborations have already begun, with a Q2 from the Centre being used in collaboration with the Hawkesbury Institute for the Environment at Western Sydney University to characterise respiration of Eucalypts.

Science and innovation are an important part of everyone's future.

PEB believes that providing the community with access to accurate information and creating a positive public dialogue about science is vital.

Science Communication

Science Communication

Education, Outreach, Media and Training

To facilitate a better and more widespread understanding of the importance of plants PEB uses its targeted Education, Outreach, Media and Training programs and resources to link the community with plant energy biology and the Centre's research.

We strive to inspire students, teachers, end-users and the general public across Australia through the delivery of engaging, informative and unique science programs. The Centre aims to equip its researchers with the skills and resources needed to broadly and effectively communicate their science.

Outreach

Our outreach programs are innovative, creative and comprehensive resources that create opportunities to communicate current research and demonstrate the role of plant energy biology in everyday life.

Plantarium, an immersive, full-dome visual showcase of PEB and its research, was launched in early 2015. *Plantarium* was created in collaboration with iVEC, the Scitech Planetarium and the University of Western Australia and was shown to over 350 people aged 4 years and above in 2015.

Bio-Bounce, a unique education resource created by the Centre, is the world's biggest and bounciest plant cell. The inflated structure houses plant cell elements and allows for an immersive and fun educational experience led by PEB staff.

Plant Powerstation is a key resource for PEB's community education and outreach. Our staff facilitate visitor participation in hands-on educational activities and interact with members of the community as part of Plant Powerstation public display stalls.

Bio-Bounce and Plant Powerstation featured at two National Science Week 2015 events. Science Alive, Adelaide saw over 2,500 excited members of the community visit PEB activities.

At Science in ACTion, Canberra PEB activities were interacted with by 500 members of the public, and through a joint initiative with the ARC Centre of Excellence in Translational Photosynthesis the workshop *Jump into the exciting world of plant cells* was delivered to approximately 100 students and members of the public at the Science in ACTion Schools Day.

Plant Powerstation was used to engage public audiences at numerous other events around Australia in 2015.

The Centre's latest fascinating photography exhibition *Plants: from micro to macro, with science in between* was displayed to over 63,302 visitors at Scitech, WA.

Outreach Highlight
Plantarium screening at Scitech Evolve Devolve

PEB relished the opportunity to participate in Evolve Devolve, an evening with Scitech's Gifted and Talented (GT) students. *Plantarium*, PEB's full-dome movie was shown to audiences of enthusiastic secondary students and their parents. Presentations by PEB scientists highlighted the important roles that evolution and genetics play in our research.

The receptive audiences took the opportunity to have their many questions addressed by PEB staff.

"I learned about insertion of new genes into plant cells and how it is achieved and why we do it."

"I think it was really interesting."

"I really enjoyed it."

(Feedback from Scitech GT students, Plantarium at Evolve Devolve)

Education

Enthusing the next generation about plant science and science careers, and creating advocates for scientific discovery is a major aim of the Centre.

PEB engages with school-aged students in a number of ways including through school incursions with visiting PEB scientists and workshops and laboratory-based excursions to educate and inform about our research.

PEB also works with teachers to equip them to teach plant science in exciting ways.

Powerful Plants, a multi-faceted, interactive science program that teaches scientific method, critical thinking and the importance of plant research has been two time runner up in the WA Premier's Science Awards. Over 200 primary and secondary students engaged in Powerful Plants in 2015.

Students learned about the power of plants, how they grow, what DNA actually is and took part in messy and exciting hands-on experiments.

Education Highlight

Powerful Plants workshop with MENSA students

PEB had the pleasure of hosting fifteen academically advanced MENSA students, aged 8 to 14 years, for an exciting half-day Powerful Plants workshop at UWA.

The bright young scientists participated in an interactive presentation about plants before examining plant cells using microscopes and setting up their own experiments to study the effects of salt on plant growth. The students extracted DNA from plant cells and discussed how the procedure acted to open up plant cells and release the DNA housed inside the cell nucleus.

"I learned that plants help us sooo much."

"After today's workshop I now LOVE science more, and would like to try some more experiments!"

"I learnt more about cells and photosynthesis!"

(Feedback from MENSA Kids, Powerful Plants)

Education Highlight

Professional Development workshop with Kimberley Teachers

In 2015 a group of proactive teachers from Western Australia's Kimberley Region visited UWA as part of the SPICE Kimberley Science Program.

PEB took the opportunity to engage them with a Powerful Plants Professional Development workshop, and provide ideas and resources for delivering curriculum-link plant science activities from the Powerful Plants program in their classrooms.

The teachers found the workshop valuable and were keen to implement the activities learned from PEB in their own classrooms.

Media

We recognise that the Australian media is an avenue to achieve broad community reach for the communication of our science. In 2015 the Centre continued its valuable affiliation with the Australian Science Media Centre (AusSMC) and established a profile on their new national online media platform, Scimex.

In 2015 PEB had over 100 mentions in the media and used print, online, television, radio and social media platforms to educate and inform the community about the Centre's science. o facilitate a better and more widespread understanding of the importance of plants PEB uses its targeted Education, Outreach, Media and Training programs and resources to link the community with plant energy biology and the Centre's research.

We strive to inspire students, teachers, end-users and the general public across Australia through the delivery of engaging, informative and unique science programs. The Centre aims to equip its researchers with the skills and resources needed to broadly and effectively communicate their science.

The page was re-launched by an enthusiastic new team in parallel with National Science Week 2015. PEB students and staff, along with scientists from a number of other Australian institutions are now creating content for, and administering the page.

"Contributing to a social media page with a global audience is a fantastic opportunity for me to communicate science" said Ghislaine Platell, a joint PhD student at PEB and the Centre for Integrative Bee Research (CIBER) and an administrator of the page.

Media Highlight
Stressed out plants send animal-like signals

PEB drew attention in 2015 with a report that in spite of not having a nervous system plants use GABA, a signalling molecule normally associated with animals, when they encounter stress. The research, published in *Nature Communications*, was performed by a team of PEB scientists at the University of Adelaide.

"We've discovered that plants bind GABA in a similar way to animals, resulting in electrical signals that ultimately regulate plant growth when a plant is exposed to a stressful environment." said senior author Centre Chief Investigator Matthew Gilliham.

The story was run over 50 times by media around the globe and featured on the Channel Eleven children's science program, Scope.

While it was known previously that plants produce GABA when stressed, the novel finding in this research was that plants use GABA as a signal to respond to that stress. In identifying how plants use GABA as a stress signal a new tool is in hand to help the global effort to breed more stress resilient crops.

Social Media Highlight
Science is Amazing re-launched

In 2015 PEB breathed new life into *Science is Amazing*, a Facebook page designed to promote public interest and engagement in science through facts, imagery and posts about topical science.

Science is Amazing was first launched by PEB in 2012 in collaboration with the International Centre for Radioastronomy Research (ICRAR). The page has gathered in excess of 20,000 followers.

Training

Professional training provides our staff and students with both the tools and confidence to be excellent scientists and science communicators.

To equip our researchers with the capabilities to effectively communicate to a broad range of audiences a number of training workshops were run for Centre staff in 2015.

The focus of these was on interacting effectively with media and social media. By building a stronger understanding of best practice interaction with the media, the Centre aims to strengthen its ability to reach Australians with accurate scientific information in the future.

Training Highlight
Media Skills for Scientists

To get comfortable with working with the media a number of PEB staff took part in a workshop delivered by freelance journalist Michelle Wheeler.

PEB scientists got to practice honing their message with working radio journalist Lisa Barnes. They then tested out their interview techniques in front of a camera with television journalist Louise Momber.

The working journalists shared their insights, expertise and tips while participants learned all about the mainstream media. Participants came away feeling more confident about working with the media and better prepared for when a reporter calls.

"I've attended a couple of media training workshops in the past and this was the best so far" said Dr Sandra Tanz, a PEB Postdoctoral Researcher. *"I really liked meeting a couple of journalists, hearing about their daily activities, and the practice in giving a radio interview and an interview in front of the camera".*

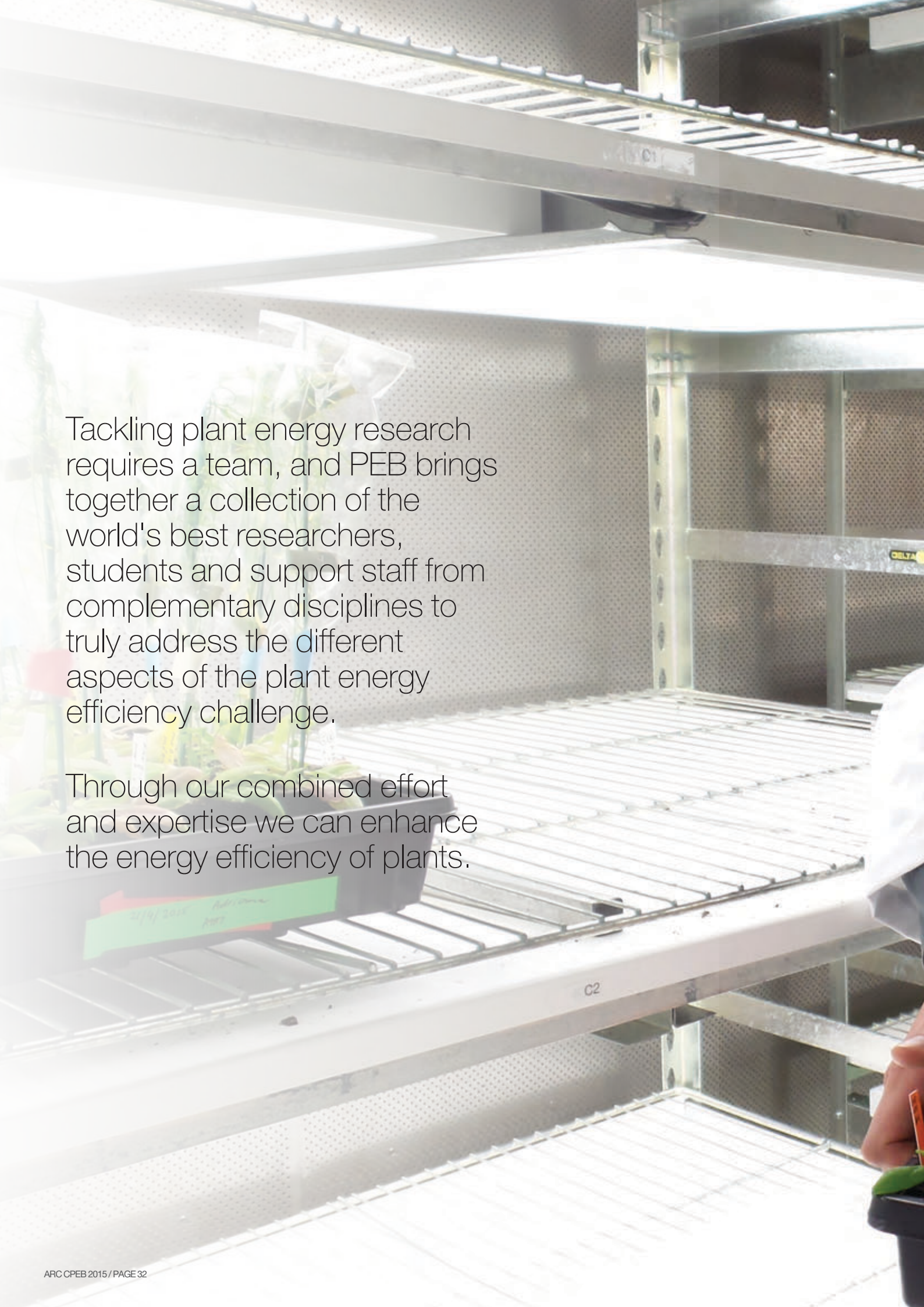
Future Initiatives

The Centre continues to explore and engage with new opportunities to communicate its science.

Work has commenced on the build of a PEB virtual reality experience. The Centre aims to develop a suite of VR experiences for immersing school and public audiences in plant science in a novel, exciting and interactive way.

PEB is excited to be partnering with Scitech to showcase its science as part of the World BioTech Tour (www.worldbiotechtour.org) which will make its way to Perth during National Science Week 2016.

In collaboration with the ARC Centre of Excellence for Translational Photosynthesis and the Australian Science Teachers Association (ASTA) PEB and will produce a number of resources for Australian science teachers. ASTA's expertise will be drawn on to help identify best links with Australian curriculum and provide broad access to educators.



Tackling plant energy research requires a team, and PEB brings together a collection of the world's best researchers, students and support staff from complementary disciplines to truly address the different aspects of the plant energy efficiency challenge.

Through our combined effort and expertise we can enhance the energy efficiency of plants.

People

Awards & Recognitions

Barry Pogson	ASPB Top Author	The American Society of Plant Biologists
Barry Pogson	Thomson Reuters 2015 Highly Cited Researcher	Thomson Reuters
Caitlin Byrt	South Australian Tall Poppy	Australian Institute of Policy and Science
Diep Ganguly	Best Paper Prize, 2015	Australian Society of Plant Scientists
Estee Tee	2015 Research School of Biology HDR Conference Award	Research School of Biology, Australian National University
Harvey Millar	ASPB Top Author	The American Society of Plant Biologists
Ian Small	Fellow of the Australian Academy of Science	Australian Academy of Science
Ian Small	ASPB Top Author	The American Society of Plant Biologists
James Whelan	ASPB Top Author	The American Society of Plant Biologists
Joshua Mylne	2015 Vice-Chancellor's Mid-Career Research Award	The University of Western Australia
Laura Boykin	Rising Star winner	The University of Western Australia, The Faculty of Science
Mark Waters	2015 Goldacre award	Australian Society of Plant Scientists
Matthew Gilliham	ASPB Top Author	The American Society of Plant Biologists
Nicolas Taylor	ASPB Top Author	The American Society of Plant Biologists
Nicolas Taylor	Robson Medal recipient	The University of Western Australia, The Faculty of Science
Nur Bahar	2015 Excellence Award	Parque Katalapi and University of Concepcion
Olivier Van Aken	ASPB Top Author	The American Society of Plant Biologists
Olivier Van Aken	2015 Vice-Chancellor's Mid-Career Research Award	The University of Western Australia
Rana Munns	Life Membership	Australian Society of Plant Scientists
Reena Narsai	ASPB Top Author	The American Society of Plant Biologists
Ronald Yu	ANU Three Minute Thesis (3MT) competition finalist	Australian National University
Ryan Lister	Metcalf Prizes for Stem Cell Research	National Stem Cell Foundation of Australia
Ryan Lister	Knowledge Nation 100	Knowledge Society
Sandra Tanz	Publication Award for Early Career Researchers	The University of Western Australia, The Faculty of Science
Sandra Tanz	Western Australian Tall Poppy	Australian Institute of Policy and Science
Shujuan Zhang	2015 Green Talents Competition winner	German Federal Ministry of Education and Research
Stefanie Wege	The Edith Emily Dornwell Early Career Research Medal	The University of Adelaide
Stephen Tyerman	ASPB Top Author	The American Society of Plant Biologists

Highlight

Plant Energy Biology's Tall Poppies
Dr Caitlin Byrt and Dr Sandra Tanz

Dr Caitlin Byrt (SA) and Dr Sandra Tanz (WA), two of PEB's early-career researchers, were named Young Tall Poppies in 2015.

The prestigious Young Tall Poppy Science Awards are presented annually by the Australian Institute of Policy and Science (AIPS). The Tall Poppy Campaign aims to recognise the achievements of outstanding young Australian scientific researchers and communicators.

The SA Tall Poppy award was presented to Caitlin in recognition of her work at PEB and at the ARC Centre of Excellence in Plant Cell Walls at the University of Adelaide, as well as her earlier scientific endeavours.

Highlights from Caitlin's research career include the discovery of two genes underling salt tolerance in wheat. Her work demonstrated that the proteins coded for by these genes help to prevent toxic build-up of sodium in leaves.

"Agricultural productivity faces big challenges" Caitlin said. *"My research involves engineering plants to improve their productivity for the food and fuel industries".*

Caitlin's research has led to successful increases in the yields of wheat in saline soils. The introduction of one of the genes identified by Caitlin and her colleagues into durum wheat resulted in a crop capable of producing a 25% increase in yield in salty soils.

Sandra's WA Tall Poppy award was presented in recognition of her work at PEB's UWA node. She has been investigating the photosynthesis of high performance C4 plants.

C4 plants have adapted to thrive in hot and dry environments. In the face of increasingly dry and arid agricultural lands Sandra's research has the potential to improve the productivity of crop plants (which typically use C3 photosynthesis) when grown under such poor conditions by equipping them with C4 photosynthetic traits.

"By investigating the photosynthetic mechanisms that exist in known high performing C4 plants, my ambition is to make the knowledge available for application in food crops grown in adverse climates" Sandra said.

Both Sandra and Caitlin have been proactive in communicating their research and related science through outreach activity. Efforts in communication and community engagement activities are criteria assessed in the Tall Poppy Campaign.

Caitlin was involved in creating the educational documentary Seed Hunter. Seed Hunter talks of the importance of genetic diversity in plant breeding in order to develop new, high yielding crops capable of coping with environmental stresses.

Seed Hunter has screened internationally, has won numerous awards and is frequently used in high school science education.

> These winners reflect the important, life changing research being carried out that will ultimately affect all of us. Their passion for communicating their work means many more will hear about the fantastic work being carried out right here in Australia

For a number of years Sandra has contributed to the Australian National Youth Science Forum and to UWA's Science Experience workshops for high school students. She has been actively involved in many of PEB's education and outreach projects.

Tall Poppy Award winners participate in education and community outreach programs in which they become role models to inspire school students and the broader community about the possibilities of science.

Personnel Highlights

PEB Students

PEB is committed to excellence in its recruitment, training and education of postgraduate students.

PEB recognises the crucial part its postgraduate students play in the Centre's success. Investing heavily in opportunities for our students to engage in technical and professional courses and training programs that enhance knowledge and skills prepares them for positions in the commercial and academic sectors and leads to successful outcomes for the Centre through the work of these high-achievers.

The Centre boasts 56 PhD, Masters and Honours students in 2015, 16 of whom commenced and 16 who successfully completed within the year. PEB students claimed a number of awards and authored numerous publications in 2015.

Highlight

Dr Kai Xun Chan began his journey with PEB in 2008, joining the Pogson team at ANU as an undergraduate Summer Research Scholar before commencing his PhD studies with the Centre in 2011. In 2015 Kai submitted and was awarded his Doctorate.

"I am interested in understanding the molecular pathways of communication between the chloroplast and the nucleus - a process called retrograde signalling" he said. *"I study retrograde signalling in the context of responses to environmental stresses such as drought and high light stress."*

"I find plant science fascinating, given the harsh environments that plants have to cope with. Unlike humans, plants can't just get up and walk away if they find their environment uncomfortable" he said. *"Plants are surprisingly complex and enterprising. This is what excites me and why I love working in this area"*

Kai was proud to have a first-author review accepted for publication in the highest ranked plant biology review journal, *Annual Review of Plant Biology* in 2015. He was an invited speaker at COMBIO 2015, Melbourne, and has given departmental seminars at the Cluster of Excellence in Plant Sciences (CEPLAS) University of Cologne, University of Heidelberg and Bonn University on his PhD research.

In 2014 he won the Young Scientist Award at the 9th International Workshop for Plant Sulfur Metabolism. An Australian provisional patent has been filed based on work arising from his PhD studies and the efforts of his colleagues in the Centre.

Kai has remained a part of the PEB team. He is now a Postdoctoral Research Fellow in the Pogson laboratory.

PEB Affiliates

PEB extends its research and builds new collaborations through its valued affiliated researchers. Our affiliated researchers are independently funded and bring both added expertise and an expanded focus to PEB. The Centre in turn provides support, access to technology and collaborative opportunities for these scientists and their staff and students.

Highlight

Dr Laura Boykin, an affiliated researcher to PEB, is applying her skills in computational biology and genomics to addressing global food security issues.

As of 2015 Laura's research program *Computational Biology for Sustainable Agriculture* forms part of the Bill and Melinda Gates Foundation initiative *African cassava whitefly: outbreak causes and sustainable solutions*. The initiative, established and funded by the Foundation, is a collective of international researchers focussed on addressing the cassava and whitefly issue.

In Sub-Saharan Africa viruses cause mass devastation of local cassava crops, a staple food source for the region. Laura and her research team use genomics and supercomputing to understand the evolution of the whitefly, the main insect vector for viruses plaguing cassava crops. Whiteflies are one of the most pervasive pests on earth and whitefly devastation is costing global agriculture billions of dollars a year.

In studying the genetics of whitefly species Laura's research is helping to control whiteflies, and thus the spread of crop destroying viruses. She intends that the genomics and high-performance computing techniques she is developing will be applied to other insect-based outbreaks in the future.

"Whitefly is a pest which is found all around the world, affecting agriculture wherever they go" she said. *"The techniques we're developing with African whiteflies can be applied with researchers and farmers all around the world".*

In 2015 Laura was named one of an exclusive number of TED Fellows. She was the winner of the 2015 UWA Faculty of Science Rising Star Award, and established herself as part of an Australian Government initiative; the Plant Biosecurity Cooperative Research Centre's Australia-Africa Plant Biosecurity Partnership (AAPBP). Laura spoke at the United Nations Headquarters in New York in late 2015 about the role her research is playing in tackling the UN Global Goal of "zero hunger".

Laura draws of PEB's technology, and through joint initiatives the Centre is benefiting from Laura's expertise as we collectively work towards improving the security of the world's crops plants.

A Scientific Advisory Committee (SAC) of six scientists and end-user representatives assist and guide the Centre.

Emeritus Professor Ian W. Dawes FAA (SAC Chair)
School of Biotechnology and Biomolecular Sciences, UNSW Australia

Emeritus Professor Dawes' research career has focused on the response of eukaryotic organisms to oxidative stress and ageing, the molecular analysis of control of one-carbon and folate metabolism in yeast and the mechanisms involved in initiation and timing of cell development. He is an editor of the journal FEMS Yeast Research and a member of the editorial boards of Yeast and the Journal of Microbiology.

Em. Prof. Dawes has been a Board Member of the Victor Chang Cardiac Research Institute and of the Australian Proteomic Analytical Facility and Chairman of the International Yeast Genetics and Molecular Biology Community. He has a BSc from the University of New South Wales, a DPhil from the University of Oxford in the UK and is a Fellow of the Australian Academy of Science.

Professor Elizabeth S. Dennis FAA FTSE
Division of Plant Industry and Distinguished Professor, UTS

Professor Dennis is one of the world's leading plant molecular biologists. She is a CSIRO Fellow whose plant research has led to tangible outcomes in Australian agriculture. Her research focuses on gene regulation, both genetic and epigenetic. As Chairman of the Multinational Arabidopsis Genome Project Prof. Dennis played a key role in mapping one of the first plant genomes.

Prof. Dennis's scientific excellence is acknowledged through numerous awards and distinctions, including election as a Fellow of the Australian Academy of Technological Sciences and Engineering; election as a Fellow of the Australian Academy of Science; the Lemberg Medal for distinguished contributions to biochemistry; the Pharmacia LKB/Biotechnology Medal of the Australian Biochemical Society for contributions to Biochemical Research and the inaugural Prime Minister's Prize for Science.

Emeritus Professor Margaret Clayton
School of Biological Sciences, Monash University

Emeritus Professor Clayton has previously held the positions of Head of the School of Biological Sciences, Deputy Dean of the Science Faculty and the Faculty's Associate Dean (Research) at Monash University. Her research career has been on the functional importance of phenolic compounds in brown algae, the reproductive biology of marine algae and molecular phylogeny of brown algae.

Em Prof Clayton was the ARC's Executive Director of Biological Sciences and Biotechnology from 2006 till 2009.

Professor Dale Sanders FRS
Sohn Innes Centre, Norwich Research Park.

Professor Sanders is Director of the John Innes Centre, internationally regarded as one of most prestigious plant and microbial sciences research centres. His career has focused on plant cell responses to environment and on plant cell nutrient acquisition and storage. He is a leading authority on mechanisms for the transport of chemical elements across plant cell membranes - mechanisms that have key roles in the control of crucial crop traits such as nutritional value, seed germination, response to drought conditions and plants response to toxins.

Prof. Sanders also works on the fundamental science of specialised plant transport mechanisms involved in signalling which have important, but poorly understood roles in plant biology. In 2001 he was elected as a Fellow of the Royal Society and awarded the European Science Prize of the Kärber Foundation.

Dr. Steve Thomas
Executive Manager - Commercial, Grain Research and Development Corporation (GRDC)

Dr Thomas is responsible for the GRDC's increased focus on partnerships with commercial enterprises and overseas research entities. As the previous Executive Manager of GRDC's Research Program portfolio he led the development and implementation of a long-term strategy for maximising the impact of research investment.

Dr Thomas has held numerous roles across the agricultural research sector, including Director level roles at the New South Wales Department of Primary Industries and research positions in plant molecular biology with the Australian Centre for Necrotrophic Fungal Pathogens and with the Carlsberg Research Laboratories in Copenhagen.

Professor Dr. Detlef Weigel FRS
Department of Molecular Biology, Max Planck Institute for Developmental Biology

Professor Weigel is a Director of the Max Planck Institute for Developmental Biology in Tübingen, Germany. His research focuses on mechanisms which are responsible for adaptive variation of plants, discovered through the interface of plant biology, developmental genetics and evolutionary genomics.

Prof. Weigel has received numerous honours for his contributions to plant and evolutionary biology, including the Otto Bayer Award (2010) and the State Research Prize Baden-Württemberg (2011). He is an elected member of the European Molecular Biology Organisation (EMBO), the German National Academy of Sciences, Leopoldina, the US National Academy of Sciences and the Royal Society of London.

UNIVERSITY OF WESTERN AUSTRALIA

Agudelo Romero	Patricia	Postdoctoral Researcher
Baer	Boris	Affiliated ARC Future Fellow
Baer-Imhoof	Barbara	Affiliated Researcher
Bates	Tiffane	Affiliated Manager
Belt	Katharina	PhD Student
Bernath-Levin	Kalia	Affiliated Postdoctoral Researcher
Bogdanovic	Ozren	Affiliated Researcher DECRA
Boykin	Laura	Affiliated Research Fellow
Brar	Kamalpreet	PhD Student
Brown	Tim	Postdoctoral Researcher
Buckberry	Sam	Affiliated Postdoctoral Researcher
Cahn	Jonathan	PhD Student
Castleden	Ian	Database/Systems Engineer
Colas des Francs-Small	Catherine	Postdoctoral Researcher
Corral	Maxime	Phd Student
Dosselli	Ryan	Affiliated Research Associate
Duncan	Owen	Affiliated Postdoctoral Researcher
Farthing	Rosemarie	Laboratory Technician
Fenske	Ricarda	Research Officer
Fisher	Mark	Honours Student
Ford	Ethan	Postdoctoral Researcher
Franklin	Amy	PhD Student
Grassl	Julia	Affiliated Postdoctoral Research Associate
Gutmann	Bernard	Affiliated Researcher DECRA
Heidarvand	Leila	PhD Student
Hewitt	Timothy	Honours Student
Hooper	Cornelia	Postdoctoral Researcher
Howell	Kate	Affiliated Researcher DECRA
Huang	Shaobai	Affiliated ARC Future Fellow
Ivanova	Aneta	Postdoctoral Researcher
Jayasena	Achala	PhD Student
Jeybalan	Jeya	Administration Officer
Karpievitch	Yuliya	Postdoctoral Researcher
Kerbler	Sandra	PhD Student
Khan	Adil	PhD Student
Kinene	Tonny	PhD student
Lee	Alex	Postdoctoral Researcher
Leroux	Julie	Research Assistant
Li	Lei	Affiliated Postdoctoral Researcher
Lister	Ryan	Chief Investigator
Mann	Julia	PhD Student
McLagan	Andrew	PhD Student
Melonek	Joanna	Postdoctoral Researcher
Millar	Harvey	Director and Chief Investigator
Millman	Michael	Honours Student
Mohamed	Sufyaan	PhD Student
Muhamad Hafiz	Che Othman	PhD Student
Munns	Rana	Chief Investigator
Murcha	Monika	Affiliated ARC Future Fellow
Mylne	Joshua	Affiliated ARC Future Fellow
Nelson	Clark	Postdoctoral Researcher
Ng	Sophia	Postdoctoral Researcher
Nonis	Sam	Honours Student
O'Leary	Brendan	Affiliated Researcher DECRA
Oliva	Marina	Postdoctoral Researcher
Petereit	Jakob	Graduate Research Assistant
Pflueger	Christian	Postdoctoral Researcher
Porri	Aimone	Affiliated Research Fellow EMBO
Pouvreau	Benjamin	PhD Student
Price	Karina	Science Communications Officer
Pruzinska	Adriana	Affiliated Researcher DECRA

Secco	David	Affiliated Researcher DECRA
Shute	Geetha	Chief Operations Officer
Simmons	Rebecca	PhD student
Small	Ian	Chief Investigator
Small	Ghislaine	PhD Student
Ströher	Elke	Affiliated Postdoctoral Researcher
Sun	Kelly	PhD Student
Szewczak	Robert	Honours Student
Tan	Dennis	PhD Student
Tanz	Sandra	Affiliated Researcher DECRA
Taylor	Nicolas	Affiliated ARC Future Fellow
Tonti-Filippini	Julian	Affiliated Postdoctoral Researcher
Troesch	Josua	Technician
Vacher	Michael	Postdoctoral Researcher
Van Aken	Olivier	Affiliated Postdoctoral Researcher
Van der Merwe	Margaretha (Marna)	Affiliated Researcher DECRA
Vargas Landin	Dulce Beatriz	PhD Student
Wainaina	James	PhD Student
Walker	Hayden	Senior IT officer
Ward	Katherine	Purchasing/Accounts Officer
Waters	Mark	Affiliated Research Fellow
Williams	Anna	PhD Student

AUSTRALIAN NATIONAL UNIVERSITY

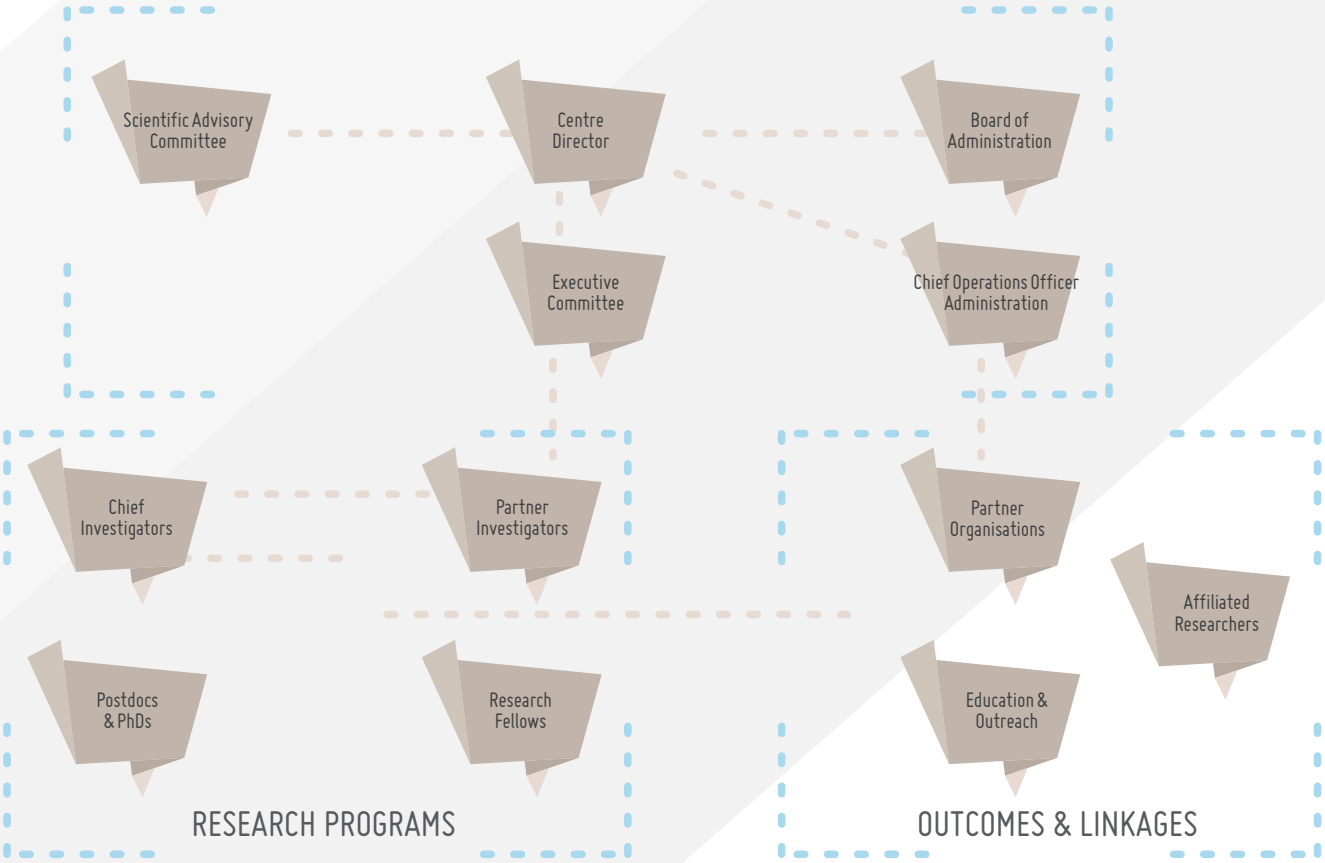
Ahmad Rashid	Fatimah Azzahra	PhD Student
Alves Negrini	Ana Clarissa	Postdoctoral Researcher
Atkin	Owen	Chief Investigator
Bahar	Nur	PhD Student
Bloomfield	Keith	Postdoctoral Researcher
Borevitz	Justin	Chief Investigator
Chan	Kai Xun	Postdoctoral Researcher
Cheng	Riyan	Postdoctoral Researcher
Collinge	Derek	Lab Manager
Crisp	Peter	Postdoctoral Researcher
Eichten	Steven	Affiliated Researcher DECRA
Fan	Yuzhen	Technical Officer
Ganguly	Diep	PhD Student
Hou	Xin	PhD student
Kariyawasam	Buddhima	PhD student
McQuinn	Ryan	Postdoctoral Researcher
Murray	Kevin	PhD Student
Nisar	Nazia	Postdoctoral Researcher
Phua	Su Yin	Senior Technical Officer
Pogson	Barry	Deputy Director and Chief Investigator
Rivers	John	PhD student
Rungrat	Tepsuda	PhD student
Scafaro	Andrew	Postdoctoral Researcher
Spence	Matthew	Technical Officer
Streich	Jared	PhD student
Stuart	Tim	PhD Student
Supple	Megan	Postdoctoral Researcher
Tee	Estee	PhD Student
Tucker	Josephine	Technical Officer
Warthmann	Norman	Postdoctoral Researcher
Watkins	Jacinta	PhD Student
Wilson	Phillipa	Postdoctoral Researcher
Worcester	Corey	Operations Manager
Xiong	Xiaofeng	PhD student
Yadav	Arun	Affiliated Postdoctoral Researcher
Zhang	You	Honours Student
Zhu	Lingling	PhD student

UNIVERSITY OF ADELAIDE

Athman	Asmini	Research Assistant
Bose	Jayakumar	Postdoctoral Researcher
Byrt	Caitlin	Affiliated Researcher DECRA
Gilliham	Matthew	Chief Investigator
Henderson	Sam	Postdoctoral Researcher
Hocking	Bradleigh	PhD Student
Kamran	Muhammad	PhD Student
Kaur	Satwinder	Masters Student
Mafakheri	Ali	Research Assistant
Qiu	Jiaen	Postdoctoral Researcher
Qu	Yue	PhD Student
Ramesh	Sunita	Postdoctoral Researcher
Scharwies	Johannes	PhD Student
Shelden	Megan	Affiliated Researcher DECRA
Sohaimi	Muhammad	Honours Student
Sullivan	Wendy	Research Assistant
Tyerman	Stephen	Chief Investigator
Vandeleur	Rebecca	Operations and Research Manager
Wang	Chuang	Postdoctoral Researcher
Wang	Lin	Masters Student
Wege	Stefanie	Postdoctoral Researcher
Wignes	Jonathan	PhD Student
Wu	Yue	PhD Student
Xu	Bo	Affiliated Postdoctoral Fellow

LA TROBE UNIVERSITY

Berkowitz	Oliver	Postdoctoral Researcher
De Clercq	Inge	Postdoctoral Researcher
Jost	Ricarda	Senior Research Fellow
Law	Simon	Postdoctoral Researcher
Linn	Joshua	PhD Student
Lu	Li	PhD student
Lyu	Wenhui	PhD student
Meng	Xiangxiang	PhD Student
Narsai	Reena	Postdoctoral Researcher
Osorio	Marina Borges	PhD Student
Radomiljac	Jordan	Research Officer
Ren	Meiyan	PhD Student
Wang	Yan	Postdoctoral Researcher
Whelan	Jim	Chief Investigator
Zanganeh	Fatemeh	PhD Student
Zhang	Botao	Postdoctoral Researcher


Scientific Advisory Committee
Centre Director
Board of Administration
Executive Committee
Chief Operations Officer Administration
Chief Investigators
Partner Investigators
Partner Organisations
Affiliated Researchers
Postdocs & PhDs
Research Fellows
Education & Outreach
RESEARCH PROGRAMS
OUTCOMES & LINKAGES

Selected 2015 Centre Publications

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2015 Publication Fast Facts

- Total number of publications by Centre staff: 88
- Average impact factor: 6.84
- Publications in top journals (impact factor 10 and above): 13
- Top journals include Trends in Plant Science, The Plant Cell, Nature Communications, Current Opinion in Plant Biology and eLife.

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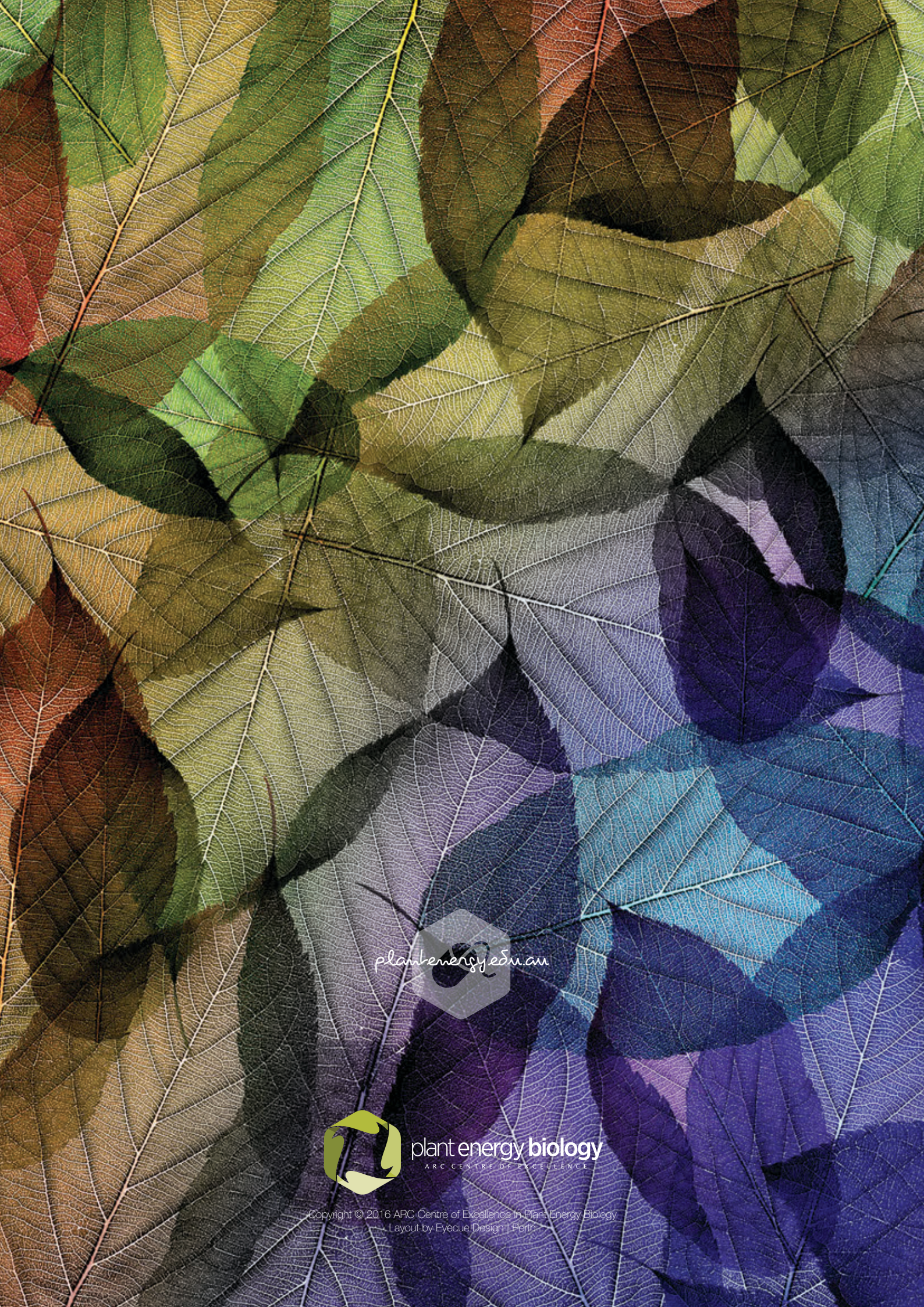

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