Annual Report 2016

Genes to Energy | Energy to Yield

plant energy biology
ARC CENTRE OF EXCELLENCE

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WE BRING TOGETHER THE BEST PEOPLE FROM AROUND THE WORLD AND PROVIDE THE RESOURCES, THE INTERACTIVE ENVIRONMENT AND THE INSPIRATION THAT ENSURES CUTTING-EDGE RESEARCH OUTCOMES.

The Centre

CENTRE OVERVIEW

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

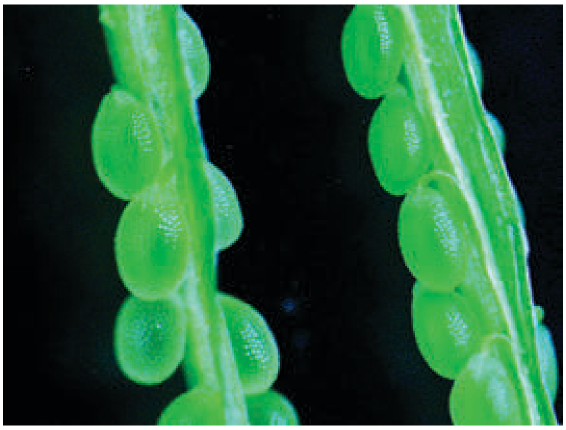
To enhance plant energy efficiency by simultaneously optimising energy capture, conversion and use in changing environments, in order to improve the sustainable productivity of plants.

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.



Tapping into the potential of plants is what drives research at the ARC Centre of Excellence in Plant Energy Biology.

Plant Energy Biology Fast Facts 2016

- 4 collaborating universities; The University of Western Australia, 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 180 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 over 115 publications in 2016.

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 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 2016 Plant Energy Biology is mid-way through its funding from the Australian Research Council which extends till 2020. The Centre's ten Chief Investigators have been leading highly productive research teams over the last three years, with major advances made in cell metabolism and signalling regulation, stress response and transport, genome wide association mapping, epigenomics and ecophysiology.

Our ground-breaking strategic research is also aiding the Australian grains industry in their aims for wheat improvement.

Find the best people

Attracting the very best young scientists to develop their projects in collaboration with us is a key focus of the Centre. This makes maximum use of the exciting intellectual environment and the modern facilities at each of our four university partners. More than 20 Future Fellows, DECRA Fellows and International Fellowship holders have joined the Centre to develop their own research programs since it began. For many of those researchers their projects are now coming to fruition with important articles led by them appearing in top international journals in 2016.

The Centre is committed to the mentoring of our staff and students and enhancing their skills to help them become independent researchers in the competitive world environment of academia, industry and government.

Our pledge in this regard was formalised in 2016 by a series of commitments in our Mentoring to Independence Program (M2I).

Through a series of events and opportunities this aims to aid independence, provide flexible skilling and ensure our staff and students build the professional networks they will need for the next phase of their scientific journey.

> Plant energy efficiency can be gained at multiple levels: through gene expression and metabolic processes, via cell specialisation and signalling, or by physiological responses to the environment

Plan the best science

Many of the projects started early in the life of the Centre are now reaching important milestones. Using citations as a metric, the Centre rivals many of the world's best known and respected plant science centres, and Centre investigators remain in demand as presenters at international conferences.

In 2016 Thomson ISI Highly Cited Researcher Awards were announced for three of the Centre's Chief Investigators (Millar, Small and Whelan), a Tall Poppy Award was given to centre postdoctoral fellow, Dr Olivier Van Aken, and nine of our PhD students won prizes or awards for their leadership, teaching and entrepreneurial skills from a variety of organisations.

With changes in funding, people and equipment comes exciting opportunities for the Centre and its staff. Our research programs are regularly reviewed, revamped, reorganised and new ones added to set new strategic directions in our research.

New research on transport systems, that use much of the chemical energy transformed in cells, has been initiated.

Much wider use of environmental simulation facilities and of genomics and epigenomic profiling of plant cells are being undertaken as we seek to explore the gene networks that control energy efficiency of plants.

Experimental flux analysis and mathematical modelling activities are being used as we seek to quantify the cellular economy of plant systems.

Collaboration is the key to innovation and the combination of different disciplines can take science in intriguing directions. PEB hosts affiliated researchers from different research areas and promotes collaboration with them. It also reaches out to collaborate with scientists nationally and internationally to lend our expertise to diverse projects.

These projects range from honeybee and whitefly research to cancer biomarkers and climate modelling and we explore in this report how we aid this process.

Use the best outcomes

As a Centre we rightly pride ourselves not only on excellent science coming from our labs, but also that our discoveries are made relevant to societal needs.

Using our expertise and knowledge we have built partnerships with industry on selected topics of interest to stakeholders. Salinity tolerance, drought tolerance, phenomics of energy traits, biomarkers in metabolism and plant hybrid systems are the current focus of these efforts.

To broaden the scope of our education and outreach program we have developed The Virtual Plant Cell (VPC) allowing users to become immersed in, and interact with, a plant cell. Through VPC, audiences can learn about the complex processes that our scientists study. It has already been viewed by several thousand members of the public, and has been overwhelmingly well received both as a virtual reality experience and as a valuable teaching resource.

Professor Harvey Millar
Director

> We are discovering 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.

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. In 2016 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 Western Australia's 2014 Scientist of the Year and named one of the world's most highly cited researchers in 2016. He co-leads Research Program 1 with Owen Atkin.

PROFESSOR RYAN LISTER

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

PROFESSOR RANA MUNNS

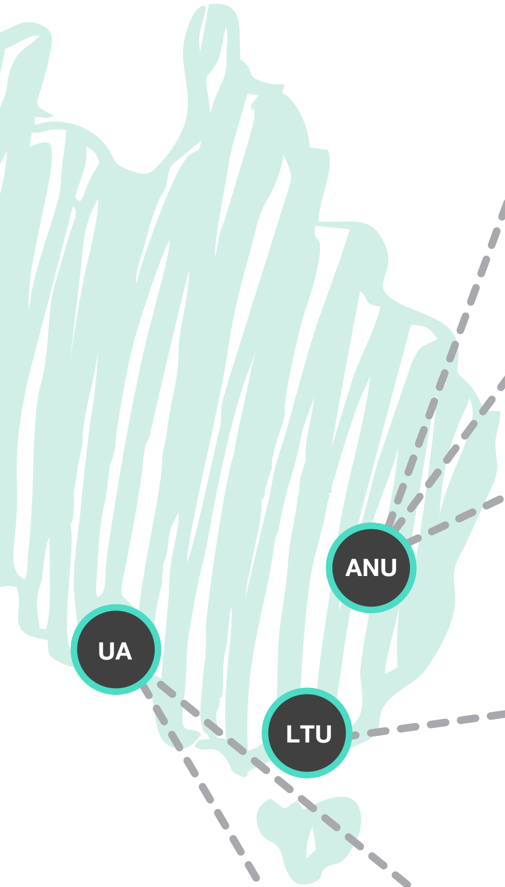
Rana's focus is on the mechanisms by which plants adapt to drought and salinity stress. Rana holds a joint position with the University of Western Australia and CSIRO Agriculture, Canberra. Rana is a Fellow of The World Academy of Sciences and is recognised internationally for her insights into the fundamental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

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. Owen co-leads Research Program 1 with Ian Small.

PROFESSOR JIM WHELAN

Jim's research combines morphological, biochemical, genetic and 'omic approaches to understand organelle function and biogenesis in plants. Jim is the Co-Director of AgriBio, Centre for Agricultural Bioscience and was named amongst the world's most highly cited researchers in 2016. Jim co-leads Research Program 2 with Matthew Gilliham.

PROFESSOR MATTHEW GILLIHAM

Matthew'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, and co-leads Research Program 2 with Jim Whelan.

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.

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

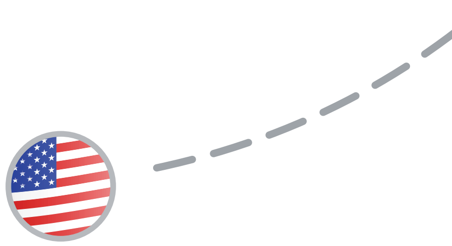
The Salk Institute focuses on discovery, and on mentoring future generations of researchers in genetics, cell and plant biology, and related disciplines. Two of its leading research professors, Joseph Ecker and Joanne Chory are partner investigators in PEB. Salk have made in-kind commitments to staff 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. Ĺsa Strand, from UPSC, is a partner investigator in PEB. UPSC provides 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 funds 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 provides 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 fund the development of instrumentation and new software for use in the Centre, and for deployment across Australia and bring imaging expertise to a number of the 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 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 provide PhD scholarships and research costs to PEB and fund projects arising from CIs' discoveries for improving salinity and drought tolerance and energy use efficiency in wheat and barley. The GRDC will give advice to t he Centre, evaluate new PEB intellectual property for further funding by GRDC, and 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 roll is in the collaborative development of rice varieties, with emphasis on use of its extensive field sites to facilitate translation from PEB's discoveries.

Through collaborative efforts with both formal and informal Centre partners PEB broadens its research capacity, draws on global expertise and produces cutting-edge research outcomes. In 2016 formal PEB partnerships resulted in a number of significant research publications in top journals.

Epigenetic diversity in the plant root tip

[Partnership: PEB-UWA, SALK Institute]

Plants are complex organisms made up of many distinct subpopulations of cells which carry out distinct functions. This enables a plant to operate as a cohesive whole. The epigenomic landscape varies between cell types and may play an important role in determining cell type identities.

For the first time cell-type specific maps of gene expression and epigenetic marks were generated for all major cell types in the plant root. Through collaborative expertise in epigenomic sequencing and analysis, researchers at PEB, The Salk Institute and Duke University were able to carefully examine the gene expression programmes employed by different cell types and the epigenomic diversity that exists between cells in the root.

The research revealed the enormous amount of variation in both the pattern of epigenetic marks, and in the patterns of gene expression that exists between cells that are physically close together in the root.

Cells of the root cap in particular were found to be far more highly DNA methylated than any other cell or tissue type found to date. It's thought that this extreme level of DNA methylation may provide a signal to nearby root stem cells to reinforce silencing of mobile DNA elements, or may play a role in defence against viruses from the surrounding environment.

The study provides new insight into the epigenomic diversity that exists between plant cell types.

Kawakatsu T, Stuart T, Valdes M, Breakfield N, Schmitz RJ, Nery JR, Urich MA, Han X, Lister R, Benfey PN, Ecker JR (2016) Unique cell-type-specific patterns of DNA methylation in the root meristem. NATURE PLANTS 2(5):16058.

Liberating phosphate for uptake

[Partnership: PEB-UA, Zhejiang University]

Much of the phosphate found in soil is in an organic form - that is, bound with carbon in various carbon-phosphate molecules. For plants to be able to access the phosphate these molecules must first be broken down to liberate the phosphate into a form that can be taken up across root membranes.

In collaboration with partner researchers at Zhejiang University, PEB scientists characterised an excreted enzyme, OsPAP10c, from the root surface of rice plants. OsPAP10c is able to break down organically bound phosphate when in the soil, significantly increasing the efficiency of phosphate utilisation by rice plants.

As a team member at PEB's University of Adelaide node, senior author of the research Dr Chuang Wang provided expertise established at Zhejiang University in phosphate mobilising transporters and aquaporins to the study.

OsPAP10c represents a novel phosphate-liberating enzyme secreted by roots that scavenges organic phosphate when phosphate is in short supply. This collaborative work has revealed the potential of OsPAP10c in practical applications for the improvement of phosphorous use efficiency in crops.

Lu L, Qiu W, Gao W, Tyerman SD, Shou H, Wang C (2016) OsPAP10c, a novel secreted acid phosphatase in rice, plays an important role in the utilization of external organic phosphorus. PLANT, CELL AND ENVIRONMENT 39(10):2247-59.

Dissecting out dynamic changes in rice

[Partnership: PEB-LTU, PEB-UWA, SALK Institute]

Rice has to survive days under water due to the seasonal flooding of the regions in which it is grown. This flooding causes periods of anoxic growth of rice coleoptiles in the absence of oxygen and of the ATP normally generated to provide energy to the growing seedling.

A collaboration between LTU and UWA PEB researchers and our Centre partners at the Salk Institute enabled an in depth analysis of the epigenetic and transcriptional changes that are associated with the shift from rice growth under water to growth after the flooding period, when air turns.

Temporal analysis of the transcriptome and methylome from germination to young seedlings under aerobic and anaerobic conditions revealed 82% similarity in the transcriptome and no differences in the epigenome up to 24 h.

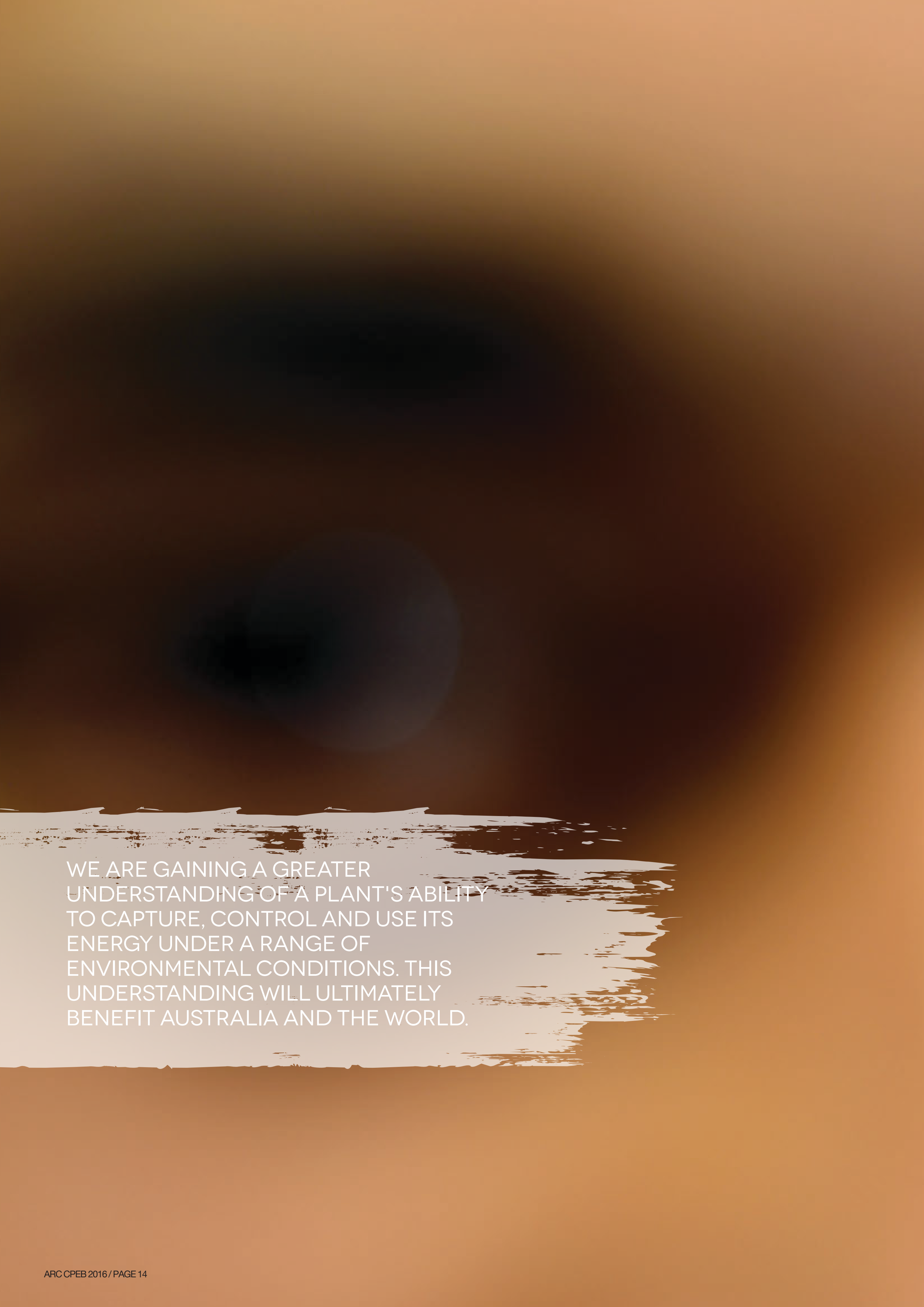
Following germination, significant changes in the transcriptome and DNA methylation were observed that showed a link between the epigenomic state and cell division. Re-oxygenation of 3-day anaerobically grown seedlings resulted in rapid transcriptomic and DNA methylation changes. Unlike the transcriptome, changes in DNA methylation upon re-oxygenation did not reflect those seen in aerobic coleoptiles, but instead, reverted to a pattern similar to dry seeds.

Reversion to the 'dry seed' state of DNA methylation upon re-oxygenation may act to 'reset the clock' for the rapid molecular changes and cell division that results upon re-oxygenation.

"The combination of expertise on rice biology, oxygen response, next gen sequencing of RNA and DNA methylation and the integrated analyses of these data required the combined expertise of all partners" said Professor Jim Whelan.

This is the first report of large scale changes in the rice epigenome in response to an environmental cue.

Narsai R, Secco D, Schultz MD, Ecker JR, Lister R, Whelan J (2016) Dynamic and rapid changes in the transcriptome and epigenome during germination and in developing rice *(Oryza sativa)* coleoptiles under anoxia and re-oxygenation. THE PLANT JOURNAL 89(4):805-824.



WE ARE GAINING A GREATER UNDERSTANDING OF A PLANT'S ABILITY TO CAPTURE, CONTROL AND USE ITS ENERGY UNDER A RANGE OF ENVIRONMENTAL CONDITIONS. THIS UNDERSTANDING WILL ULTIMATELY BENEFIT AUSTRALIA AND THE WORLD.

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 constitutes 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 to 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

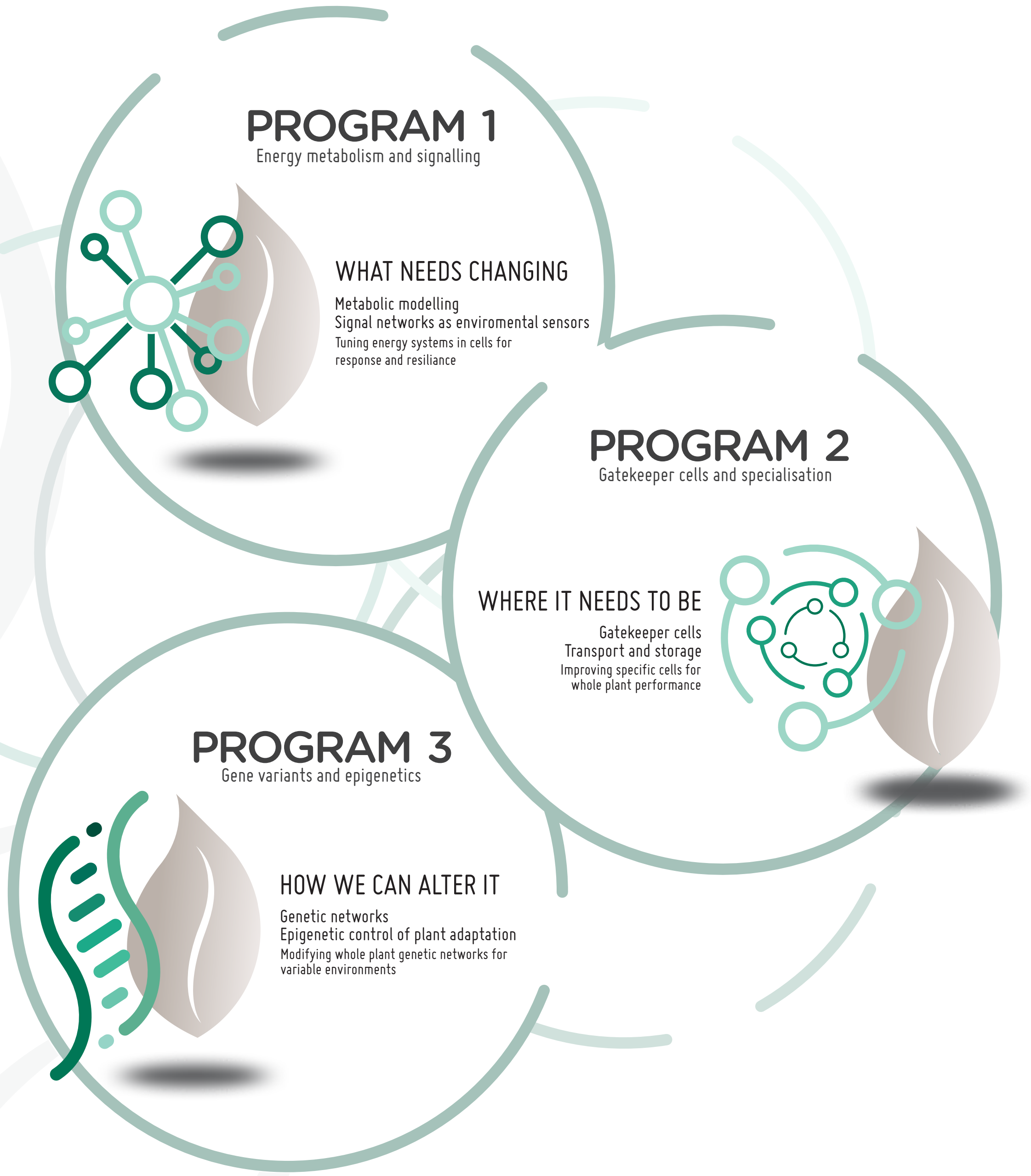
Many of these partial losses occur due to limitations and reduced efficiency in interconnected metabolic processes. Thus, small efficiency gains in the multitude of processes beyond carbon capture, but before harvest, can combine to have a magnified benefit on yield.

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.



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

Program 1 will define which 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 I

ENERGY METABOLISM AND SIGNALLING

Program leaders: Ian Small and Owen Atkin
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

Dr Peter Crisp has been involved with PEB as an undergraduate, honours and PhD student and, most recently, as a postdoctoral researcher. A major part of his research has focused on understanding the role and importance of post-transcriptional processes in plant stress responses and retrograde signalling.

"How chromatin, gene expression and post transcriptional processes shape the interactions between plants and the stressful and dynamic environments they grow in is of great interest to me".

In an exciting project, he examined if plants remember or forget stress, how quickly they forget stress and what mechanism promote forgetfulness. His 2016 Science Advances review article on the topic, Reconsidering plant memory, intersections between stress recovery, RNA turnover and epigenetic, drew significant media attention.

Peter has recently taken up a Postdoctoral position at the University of Minnesota and will study the epigenetics of maize.

Research Highlight
A drought stress alarm in plants

Adverse conditions such as drought and high light levels trigger oxidative stress in plants, inducing excess production of reactive oxygen species (ROS) and altering the chloroplast redox poise. Chloroplasts are known to respond to these challenges with multiple chemical signalling pathways to the nucleus, triggering stress response mechanisms. What remained unknown until recently was how oxidative stress is initially sensed in the chloroplast in order to activate this response.

To address this, a multinational team of researchers led by PEB probed a key drought stress chloroplast signalling pathway involving the enzyme SAL1 and its substrate, PAP. Previous Centre research had established that PAP accumulates during drought stress and alters the expression of many stress-responsive genes. Centre scientists have now elucidated how changes in ROS and redox state in the chloroplast can be sensed in order to regulate PAP levels and activate its downstream signalling.

This latest study shows that the molecular structure of the SAL1 enzyme can be directly altered through interactions with ROS or redox-reactive molecules during oxidative stress, significantly decreasing SAL1's enzymatic activity against PAP and allowing the PAP stress signal to accumulate and activate multiple stress responses.

The SAL1-PAP regulatory mechanism is highly conserved across the plant kingdom, including in key agricultural crop species, indicating the importance of this mechanism. The Centre is now working to exploit these findings in the development of more energy-efficient and stress-resilient crops during drought.

Chan KX, Mabbitt PD, Phua SY, Mueller JW, Nisar N, Gigolashvili T, Ströher E, Grassl J, Arlt W, Estavillo GM, Jackson CJ, Pogson BJ (2016) Sensing and signaling of oxidative stress in chloroplasts by inactivation of the SAL1 phosphoadenosine phosphatase. PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES USA 113 (31):4567-4576.

Research Highlight
Global patterns for respiration response to temperature

Climate models are routinely used to predict how warm the Earth will be later this century. Central to such models is predicting carbon flows between plants and the atmosphere, of which plant respiration is a major source of carbon released. It's been known for some time that the assumption routinely applied to climate models, that respiration doubles with increasing temperature, is incorrect. However, sufficient knowledge of the actual patterns in the temperature response of plant respiration has been lacking.

Researchers from PEB, together with an international team, examined plants from habitats all over the world in order to quantify the temperature response of leaf respiration in natural environments. The respiration rates of vegetation at eighteen remote sites around the world, representing seven different types of plant habitat were examined. Despite the diversity in the plant types surveyed the results point to similarities in how different plants alter their respiration rate in response to increasing temperature.

The findings hold important implications for model predictions of plant growth and accumulation of carbon dioxide in the atmosphere, and for climate modelling for the future.

Heskel MA, O'Sullivan OS, Reich PB, Tjoelker MG, Weerasinghe LK, Penillard A, Egerton JJ, Creek D, Bloomfield KJ, Xiang J, Sinca F, Stangl ZR, Martinez-de la Torre A, Griffin KL, Huntingford C, Hurry V, Meir P, Turnbull MH, Atkin OK (2016) Convergence in the temperature response of leaf respiration across biomes and plant functional types. PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES USA 113(14):3832-7.

Research Highlight
A safety valve for energy production

A hallmarks of aerobic respiration in all organisms is the formation of reactive oxygen species (ROS). These molecules can react readily with nucleic acids and proteins to alter their chemical structures and can cause extensive damage to cell structures and perturbation of metabolism when accumulated.

In the inner membrane of mitochondria, redox reactions carried out by the respiratory chain provide a chemical force that drives the generation of energy by ATP synthase. However, there is often a mismatch in the activity of the respiratory chain and ATP synthase, which can result in a higher rate of ROS production. Maintenance of a balanced redox state at the inner membrane, to avoid excessive ROS, can occur through altering ion permeability to the inner membrane. However, until recently, little was known of the identity of ion channels or the carriers responsible for this maintenance.

Centre researchers, in collaboration with an international team, recently identified MSL1 as a mitochondrial inner membrane stretch-activated ion channel that plays an important role in maintaining mitochondria redox status. Results show that MSL1 function becomes more important under specific conditions known to require fine-tuning of the mitochondrial redox balance, such as heat and heavy metal stress, effectively serving as a safety valve for energy production.

Lee CP, Maksaev G, Jensen GS, Murcha MW, Wilson ME, Fricker M, Hell R, Haswell ES, Millar AH, Sweetlove L (2016) MSL1 is a mechanosensitive ion channel that dissipates mitochondrial membrane potential and maintains redox homeostasis in mitochondria during abiotic stress. THE PLANT JOURNAL 88(5):809-825.

PROGRAM II

GATEKEEPER CELLS AND SPECIALISATION

Program Leaders: Matthew Gilliham 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, global supplies of phosphate are running out. Being an essential macronutrient for plants, growth and yield can be severely limited when phosphate is not supplied as a fertiliser.

Acquisition of necessary nutrients, control of resource transport and the exclusion and cellular detoxification of harmful substances are energy intensive for plants. To secure our future food security we require plants that 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, leading to 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 links 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

Dr Ricarda Jost leads the phosphate research group under CI Professor Jim Whelan at PEB's La Trobe University node. She seeks to improve plant phosphorus use efficiency in order to optimise fertiliser use and avoid nutrient run-off.

“The most exciting part of my work is to discover new clues as to how plants have evolved to cope with a challenging environment. I enjoy collaborating with people from across the globe, visiting their labs, and working with students and colleagues from diverse backgrounds” she said.

In 2016 she was an integral part of public campaigns centred on 'Protecting Global Food Supplies' and 'Phosphate - a story of plants, science and our survival', run by La Trobe University to communicate and promote her group's research.

“Optimising fertiliser use for more sustainable agriculture is a worldwide challenge, so our group constantly exchanges ideas with like-minded groups in Europe and China. Working together is important to promote our message and alert the public to the enormous challenges that future generations will face to match food production with population growth”.

Personal Success

Dr Jayakumar (Jay) Bose' research interests stem from growing up on a small South Indian farm with salty soils, and questioning as a child why certain crops were better-suited than others to grow. This interest led Jay to pursue studies in soil science and agriculture before moving to Australia and into ion transport mechanisms research in plants.

Jay has published 29 articles in top plant science journals since 2010, as well as six book chapters in the field. Since joined PEB in 2015 he has been awarded the Daniel Walker Medal by the University of Adelaide in recognition of early-career research excellence, and a Discovery Early Career Research Award. He values the potential for his research to translate into important real-world outcomes for farmers.

"Soil salinity is a major threat to agriculture throughout the world. Given the narrow nature of genetic diversity for salt tolerance within crops, the introduction of salt-tolerant genes from naturally salt-loving plants has real potential in tackling this issue".

As a DECRA awardee Jay intends to use closely related, model salt-sensitive and salt-tolerant plants to identify ion-transport genes that allow chloroplasts to maintain light utilisation and CO^2 fixation during salt stress. He feels the extensive research and mentoring support given at PEB have helped greatly in his success in identifying genes that confer salt tolerance to the photosynthetic machinery of plants.

Research Highlight
Water channels with ion transport mechanisms

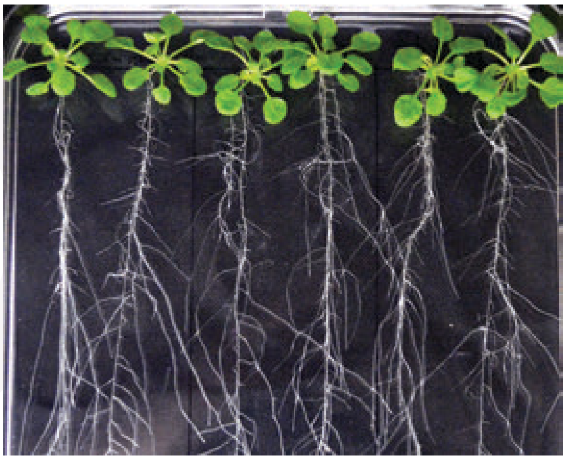
In all Kingdoms of life the rapid movement of water across cell membranes is facilitated by aquaporins. Approximately thirty different aquaporins exist in plants, with some facilitating the transport of small neutral solutes or gasses such as urea and carbon dioxide.

Until the discovery by Centre researchers of an aquaporin that can conduct sodium ions it was thought that plant aquaporins excluded charged molecules. The discovery indicates that a subset of plant aquaporins can transport both water and cations, and sheds light on a 20-year old mystery in plants by revealing a possible mechanism for root sodium and potassium uptake.

Centre researchers determined that ion transport by the aquaporin AtPIP2;1 was inhibited by calcium and protons, in a manner that is reminiscent of the characteristic way that non-selective cation channels let sodium and potassium into plant roots. This finding suggests that a subset of aquaporins may transport ions in plants and could be involved in nutritional potassium uptake and the uptake of salt into roots from saline soils.

Centre researchers are now tackling the challenge of exploring the significance of aquaporin ion transport in plant nutrient and osmotic homeostasis processes. This research was supported by Dr Caitlin Byrt's Discovery Early Career Research Award.

Byrt CS, Zhao M, Kourghi M, Bose J, Henderson SW, Qiu J, Gilliham M, Schultz C, Schwarz M, Ramesh SA, Yool A, Tyerman S (2016) Non-selective cation channel activity of aquaporin AtPIP2;1 regulated by Ca2+ and pH. PLANT, CELL AND ENVIRONMENT doi: 10.1111/pce.12832.



Research Highlight
Controlling chloride build up in shoots

Chloride (Cl^-) is an essential nutrient and plays multiple regulatory roles in plants. In soils that contain significant sodium chloride (salt) concentrations, Cl– can accumulate to high concentrations in plant shoots, leading to reductions in growth and potentially resulting in death.

The molecular targets of Cl^- toxicity and transport are, however, largely unknown and as such research into chloride tolerance has for the most part been neglected in preference of studies on sodium tolerance.

Recently, PEB researchers uncovered the first of a number of proteins involved in directly regulating Cl^- accumulation in shoots and the role of AtSLAH1 in loading the root xylem with Cl^- was determined. This was confirmed in the same year by Professor Rainer Hedrich's group at the University of Würzburg, who showed that AtSLAH1 needs to interact with AtSLAH3 in order to control Cl^- transport activity.

Through a resultant collaboration, PEB researchers are combining efforts with Prof. Hedrich's group to further understand this process. The studies have highlighted the importance of these proteins in regulating plant shoot Cl^- accumulation and indicate potential ways forward to further improve plant salinity tolerance. This project is supported by Prof. Matthew Gilliham's Future Fellowship.

Qiu J, Henderson SW, Tester M, Roy SJ and Gilliham M (2016) SLAH1, a homologue of the slow type anion channel SLAC1, modulates shoot Cl– accumulation and salt tolerance in *Arabidopsis thaliana*. JOURNAL OF EXPERIMENTAL BOTANY 67(15): 4495-505.

PROGRAM III

GENE VARIANTS AND EPIGENETICS

Program Leaders: Ryan Lister and Justin Borevitz
Program 3 focuses 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 adaptive traits. The molecular basis of these traits 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 components underlying complex traits of an organism, it may be important to understand the epigenetic codes that govern where and when the genetic information is used. Epigenetic modifications that do not alter the genome sequence but that can regulate the readout of the underlying genetic information may be environmentally sensitive and/or heritable.

Knowledge of the underlying variation that governs complex plant functions will allow selection and engineering of plants for future variable environments to be done with far more precision.

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 high yield in optimal environments has resulted in elite varieties that often do not possess the resilience found in natural populations. We can now tap into a more wild molecular genebank 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 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 evidence that the plant epigenome undergoes specific changes in response to challenging environmental conditions.

  We have investigated the role of epigenetic plasticity in plant multigenerational responses to challenging environments. Understanding the extent to which multigenerational epigenomic variability influences genetic and phenotypic variation under challenging conditions will determine the extent to which control of these process can generate stable and resilient plants in the future.

  We observe changes in the epigenome in response to a range of stress conditions. Detailed examination is indicating that these changes can, at least partially, be transmitted through mitosis, but not passed onto subsequent generations.

- **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 induce (epi)alleles in plants. Novel approaches to precision editing of epigenetic patterns and new and 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 are currently seeing these approaches working with genomic specificity in cell lines.

We are targeting phenotyping of 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 and selection of plants that with altered growth and energy efficiency under limiting and variable conditions of the future.

Personal Success

Tim Stuart studied under Ryan Lister as an undergraduate student, before continuing on to do his honours and PhD studies with the Centre. As a PhD student he is researching the genetic and epigenetic variation that exists in plant populations. His efforts resulted in his involvement in several key publications for 2016. He was the first author of two of these papers, detailing the unique cell type-specific patterns of DNA methylation in root meristems, and describing population scale mapping of transposable element diversity in plants, respectively.

"What I enjoy most is the opportunities I have to use the most cutting edge technology. I get to do research with DNA sequencers that fit in your pocket, and machines that sequence RNA from single cells — both hot topics in genomics and both would have been inconceivable even 5 years ago" he said.

"Being part of PEB goes a long way towards being able to access these new technologies and get the most out of them."

Personal Success

Dr Tim Brown brings to PEB an avid interest and expertise in building open-source tools for data visualisation and management, and in enabling low-cost, high-throughput phenotyping for lab and field applications. He has applied his expertise to the development of many unique research tools, and is excited by the potential that phenomics has to make a very significant impact on plant science and people's lives.

"High-throughput phenomics generates immensely complex datasets and a serious challenge faced by researchers is data overload" he said.

Tim's 2016 article on Phenocams describes a framework for standardising data from digital cameras used for environmental monitoring. He led the 2016 launch of the Australian Phenocam Network, and played a pivotal role in organising the AusPheno 2016 - 5th International Controlled Environment Conference.

This brought together a multi-disciplinary group of researchers ranging from NASA scientists studying LED lighting to grow food on Mars, to a paleo-climatologist using growth cabinets to reproduce ancient earth atmospheres and study plant evolution.

"I believe the phenomics challenge of the next five years is to develop data management, visualisation and analysis tools that enable scientists to understand how genetics and environment interact to create plant "behaviour", in unprecedented detail".

Tim has also been exploring the use of Virtual Reality as a tool for data visualisation and education. His EcoVR project, for the visualisation of time-lapse environmental and phenomic data, was a featured installation at the 2016 Canberra International Film Festival.

"I love working for PEB at ANU. There are so many exciting multi-disciplinary things happening in the field of plant biology and new technology".

Research Highlight
Population scale mapping of transposable elements

Transposable elements (TEs) are DNA sequences capable of deliberately changing genomic location and of self-replicating. While the presence/absence of TE copies is known to be a major source of genetic variation, a comprehensive analysis of TE variation had not been undertaken in plants.

Through a novel methodology developed by PEB researchers, TE variants in a large population of the model plant Arabidopsis were mapped and over 20,000 new genetic variants due to TE positional variation were discovered. Some of these TE variants were found to have an important effect on nearby DNA sequences.

Many were associated with an increase in DNA methylation levels, an epigenetic silencing mark normally targeted to TEs. The PEB researchers also found that the expression of nearby genes could be affected by the insertion of a TE, and in one case these gene expression changes were associated with a decrease in disease resistance.

This knowledge provides a deeper understanding of the genomic impacts of TEs. The next challenge will be to apply the methods developed to non-model species and to crop plants to further explore TE variation among different plant populations.

Stuart T, Eichten SR, Cahn J, Karpievitch YV, Borevitz JO, Lister R (2016) Population scale mapping of transposable element diversity reveals links to gene regulation and epigenomic variation. ELIFE 5. Pii:e207777.

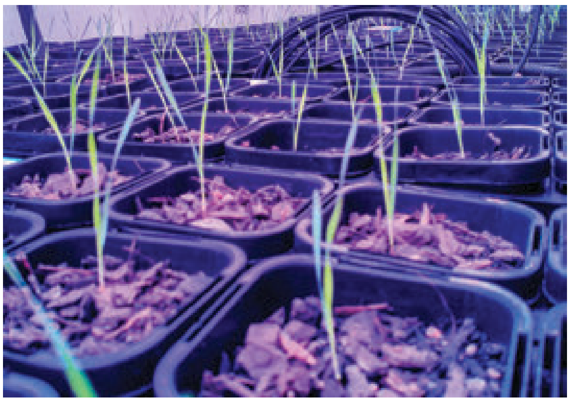
Research Highlight
Dissecting methylation's (lack of) independence

Specific biochemical marks on DNA, such as cytosine methylation, play a role as a form of epigenetic regulation of the genome. A core question of the Centre is how these epigenetic signals influence plant growth and adaptation to their environments.

Profiling of DNA methylation in the model grass *Brachypodium distachyon* was conducted by PEB researchers to determine how this modification varies between genetic backgrounds and relates to DNA polymorphisms and transposable elements in the genome. Although differences in methylation were commonly found these changes appeared tightly linked to small genetic changes (SNPs), but surprisingly unlinked to transposon variation between samples.

From this, it appears that DNA methylation may not always act independently to the underlying changes in DNA sequence. The study highlights the importance of establishing the genetic variation that exists between experimental samples before drawing conclusions about what is truly epigenetic when relating results to phenotypic outcomes.

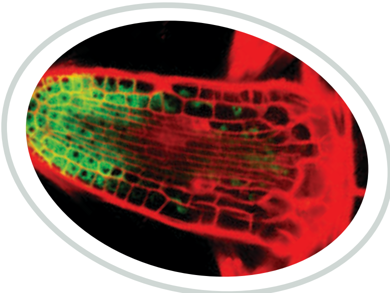
Eichten SR, Stuart T, Srivastava A, Lister R, Borevitz JO (2016) DNA methylation profiles of diverse *Brachypodium distachyon* align with underlying genetic diversity. GENOME RESEARCH 26(11):1520-31.



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.



PROGRAM 2

Genomic Approaches For Phosphate Use Efficiency Improvement

Phosphate remains a major cost as a fertiliser and a significant limiter of plant growth in harsh nutrient-limited environments. We still require fundamental knowledge of how plants gain and retain phosphate in order to make them more efficient users of this limiting resource.

Three "genomic" approaches are being undertaken by the Centre to make discoveries to alter the phosphate relations of plants. Firstly an iterative analysis of co-expression, enrichment and protein-interaction networks is being used to identify novel, cell-specific regulators of phosphate uptake and use in plants. Secondly, we are screening Arabidopsis accessions for differences in responses to phosphate limiting conditions. Thirdly we are using SPX4-Luc in a forward genetic screen to identify regulators of phosphate sensing. These projects are aimed to identify novel genes for Phosphate Use Efficiency in plants that can be transferred to our academic or commercial partners for evaluation and study under field conditions.

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.

Energy Efficiency To Improve Wheat Yield

According to The Food and Agriculture Organisation of the United Nations global crop yields must double by 2050 to meet future food security needs. To address this need Agriculture Ministers of the G20 nations established the International Wheat Yield Partnership (IWYP), a unique, international funding initiative to co-ordinate worldwide wheat research efforts.

The PEB-led IWYP project *Improving Wheat Yield By Optimising Energy Use Efficiency* is employing a novel approach combining cutting-edge molecular techniques with traditional breeding to exploit the energy systems of wheat plants and dramatically improve their yield. The team from PEB, together with the ARC Centre of Excellence for Translational Photosynthesis and the International Maize and Wheat Improvement Centre (CIMMYT), in Mexico, are combining genetics, gene expression and growth studies with the high throughput analysis of photosynthesis and respiration in order to screen elite wheat germplasm from field trials in Australia and Mexico over the next three years.

RAM 1

PROGRAM 3

Mapping Epigenomes

Technologies developed in model plants 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.

Collaborations with the Salk Institute for Biological Studies as well as affiliated Fellows in PEB have demonstrated that epigenetic mapping technologies and the study of *de novo* methylation patterns can be applied to the generation of complete epigenome maps to better understand the evolution of methylation patterns in vertebrate embryogenesis, retinal photoreceptors and brain neurons, as well as the genome evolution of polyploid animals and plants. Unlocking the secrets of plant biology may thus have far reaching benefits that can be translated to other fields of research, including human health and development, and animal evolution.

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.

MULTIDISCIPLINARY RESEARCH THROUGH COLLABORATION

Multidisciplinary research brings together unique skills and perspectives in order to solve problems. PEB extends its research outcomes through multidisciplinary research in two ways: the Centre hosts a number of Affiliate Researchers with distinct expertise and collaborates with them in their research; and PEB engages in national and international collaborative projects with individuals and organisations from different disciplines.

AFFILIATED RESEARCHERS

Protecting plant pollinators

Collaboration with CIBER and Better Bees of WA

A collaboration between affiliated Researchers from the Centre for Integrative Bee Research (CIBER), led by Prof. Boris Baer, Western Australian bee keepers and PEB scientists is helping to understand *Nosema* infections that are damaging Australian honeybees and pollination services. The multidisciplinary study has already resulted in two valuable research outcomes, published in the *Proceedings of the Royal Society* and the *Journal of Proteome Research*. The finding that honey bee seminal fluid contains mechanisms to combat the sexually transmitted *Nosema* infection, and the subsequent proteomic dissection of this immune response could help to clarify how honeybees might be protected from fungal disease in the future.

Supercomputing to tackle the Whitefly

Collaboration with Dr Laura Boykin and Bill and Melinda Gates Foundation

The computational biology and genomics expertise of Dr Laura Boykin, an Affiliate Researcher of PEB, is being applied to the study of whitefly genetics to tackle diseases that affect Cassava crops in Africa. The research is assisting in the control of whiteflies, responsible for the spread of crop-destroying viruses. The research, which forms part of the Bill and Melinda Gates Foundation initiative *African cassava whitefly: outbreak causes and sustainable solutions*, draws from PEB's technology, and through joint initiatives the Centre is benefiting from Laura's expertise as we collaborate towards improving the security of the world's crops plants.

Biomedical applications from plant evolution

Collaboration with Dr Joshua Mylne

PEB's Affiliate Researcher Dr Joshua Mylne leads research examining the genetic events that evolve new plant proteins, with particular focus on those with pharmaceutical applications. Joshua collaborates with Centre staff and combines the discipline of plant biology with biomedical research and biochemistry to provide fundamental new knowledge about protein evolution and opportunities to engineer plants to produce valuable molecules.

MULTIDISCIPLINARY COLLABORATION

Development of research databases to aid new discoveries

Collaboration with Australian National Data Service and Librarians

With the support of the Australian National Data Service (ANDS), multiple PEB-led projects are underway nationally to develop valuable research databases that allow new hypotheses to be generated and predictions made and tested to aid agricultural biotechnology. The construction of these databases is drawing on the combined expertise of Librarians, ANDS Informaticians and PEB scientists. UWA Library staff have worked with PEB-UWA researchers to create CropPAL, a compilation of subcellular protein locations for crop species. A new database for transport processes in crop species is being constructed from aggregated experimental data through a collaboration between University of Adelaide Library staff and PEB-UA, while a browser to display RNA-seq data for rice gene expression research is being created through a collaboration between La Trobe University Library staff, bioinformaticians and PEB-LTU. Each project enables end-users to aggregate evidence, allowing a birds-eye view of biological mechanisms that can be used to design improvements in crop growth and development.

Factoring plants into climate modelling

Collaboration with multiple organisations

Through a multi-organisation collaboration funded by the National Science Foundation (NSF), PEB-ANU researchers are contributing to evidence-based climate modelling for the future. Accurate prediction of carbon flow between plants and the atmosphere, of which plant respiration is a major source of carbon released, is central to climate models for the prediction of future global warming. In the most comprehensive study of plant respiration responses to temperature ever conducted the respiration rates of vegetation at eighteen remote sites around the world, representing seven different types of plant habitat, were examined in this collaboration. A new equation that describes the temperature sensitivity of leaf respiration of global vegetation will now enable global climate models to account for acclimation responses of plant respiration.

Engineering plant phenomic facilities

Collaboration with LTU School of Engineering and Mathematical Sciences

Collaborations between PEB researchers at LTU, ANU, and engineers from the School of Engineering and Mathematical Sciences at LTU are designing and constructing new phenotyping platforms to retrofit into plant growth chambers and rooms. Based on LED light systems and incorporating image analysis systems to track plant growth developed by engineers at LTU, this collaboration aims to form an advanced, energy efficient product. It combines the expertise of plant science researchers, electrical engineering solutions, and experts on lighting systems and image analysis to form an integrated product with wide applications for adoption by plant science research organisations.

Transcriptomics for cancer progenitor markers

Collaboration with multiple medical research organisations

In collaboration with cancer researchers, PEB provided transcriptomic expertise and infrastructure to a meta-analysis comparing Liver Progenitor Cell (LPC) lines against datasets of muscle and embryonic stem cell lines and embryonic and developed liver, in order to establish a signature of distinguishing markers to characterise liver pathologies harbouring LPCs. The study identified markers which specify the presence of LPCs in pathological liver tissue and correlated immunohistochemically with LPC abundance. These results demonstrate the value of a multidisciplinary approach to a scientific challenge, and resulted in a publication in the journal *Stem Cells International.*

WE SEEK TO IMMERSE PEOPLE IN OUR SCIENCE, TO EXCITE THEM AND EDUCATE THEM. WE WANT THE COMMUNITY TO KNOW THE IMPORTANCE OF PLANT ENERGY BIOLOGY RESEARCH.

Science Communication

Education, Outreach, Media and Training

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

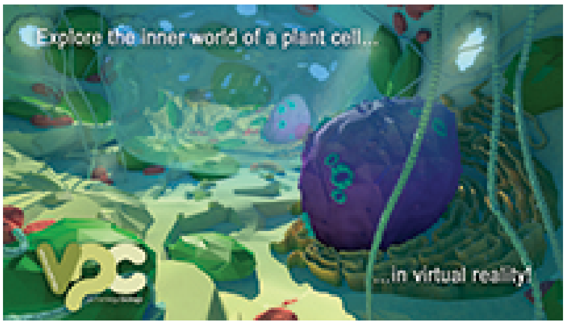
We strive to inspire students, teachers, end-users and the general public through the delivery of engaging, informative and novel science programs. PEB also aims to equip its researchers with skills and resources necessary to broadly and effectively communicate their science.

Outreach

PEB's outreach programs use innovative, creative and comprehensive resources that create opportunities to communicate our current research and demonstrate the roles of plant energy biology in everyday life.

The Virtual Plant Cell (VPC), PEB's newest education and outreach resource, capitalises on current Virtual Reality technology to teach plant cell biology and communicate the research of the Centre in a fun, innovative and highly engaging way.

VPC was developed, piloted and launched by the Centre in 2016 and has already been viewed by several thousand members of the public. The Centre plans to continue the development and use of this exciting teaching tool.



Outreach Highlight
VPC launch at National Science Week

VPC allows users to become immersed in, and interact with, a plant cell to learn about the complex processes that PEB's scientists study.

The Centre launched VPC on mobile devices during National Science Week 2016, using it to engage with public audiences at Perth Science Festival's World Biotech Tour, Canberra's Science in ACTion Festival and ANU Open Day, at the University of Adelaide Open Day and even at the Edinburgh Digital Entertainment Festival in the UK.

Audience reception of VPC has been overwhelming and its effectiveness as a teaching tool widely recognised.

"Magnificent content, really enjoyed exploring the parts of the cell."
"A really clear way of illustrating an abstract concept. Great for visual learners."
"Loved it - great idea. So many of my students think cells are 2D!
(Feedback on VPC from Perth Science Festival visitors)

Plantarium, an immersive, full-dome visual showcase of PEB and its research, is routinely played in combination with Q&A sessions with PEB scientists so that enthusiastic audiences can learn about PEB's research and have their questions addressed.

Bio-Bounce, a unique education resource created by the Centre, is the world's biggest and bounciest plant cell. The inflated structure houses elements of a plant cell and allows for an immersive, 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 learning activities and interact with members of the community as part of public display stalls.

PEB's VPC, Plantarium, Bio-Bounce and The Plant Powerstation were used extensively by the Centre throughout 2016 to engage audiences in plant science.

Through a collaboration with the Landsdale Farm School in Perth, PEB's photography exhibition Pollination: All's Fair in Love and War was exhibited to over 9,000 visitors in the School's public resource centre in 2016.

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 engage 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.

Powerful Plants, a multi-faceted, hands-on science program that teaches scientific method, critical thinking and the importance of plant research has been a two time runner up in the WA Premier's Science Awards.

Over 200 primary and secondary students engaged in Powerful Plants in 2016. Students learned about the power of plants, how they grow, what DNA is and took part in messy and exciting hands-on experiments at schools and as part of the South Australian and Western Australian ConocoPhillips Science Experience events.

In 2016, PEB's ANU scientists continued their extensive involvement in the Melrose Senior High School's Academic Curriculum Enrichment (ACE) science program.

The program is an advanced, novel science program for year 8 to 10 students. PEB's involvement in the program includes visits to the school and presentations by PEB scientists, tours of PEB facilities and mentorship of select students as part of the ACE Mentors Program.

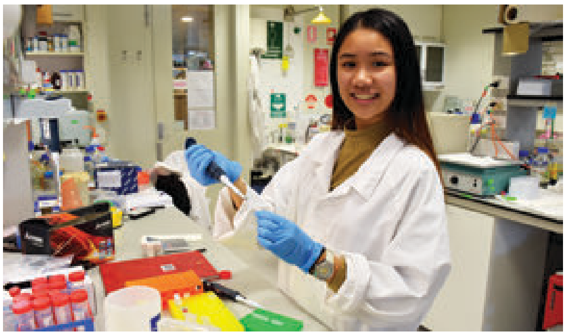
Education Highlight

Mentoring young science ambassadors

PEB scientist **Dr Kalia Bernath-Levin** had the rewarding experience of mentoring enthusiastic Year 11 student Linda Diep in 2016, as part of the World Biotech Tour Ambassadors program. Linda was selected as one of six World Biotech Tour Ambassadors from Perth schools.

Under Kalia's guidance Linda undertook a research project titled "Designing new RNA binding proteins", and presented her findings to several audiences.

"Actually experiencing making the mutations myself and researching methods to understand them was beyond what I was expecting. It has really opened my eyes to how biotechnology has impacted science and in turn, the world around us" Linda said.



Media

PEB recognises that the Australian media is an avenue to achieve broad community reach for the communication of our science.

In 2016 the Centre continued its valuable affiliation with the Australian Science Media Centre (AusSMC) and its presence on Scimex, the online breaking science news portal for Australia and New Zealand.

PEB also launched an Instagram page to showcase the stunning imagery of the Centre and educate audiences through a visual medium

Media Highlight

Plants are 'in touch' with the world

PEB scientist **Dr Olivier Van Aken** had the exciting experience of telling the world about the elaborate cellular response plants enact after being touched, drawing attention to his research publication in the journal *Plant Physiology* in early 2016.

The study, performed by a team of PEB researcher lead by Olivier, suggested that this touch response prepares a plant to defend itself from danger or take advantage of changes in the weather, drew significant attention from the media. The story was run over 60 times online, in print and over the radio.

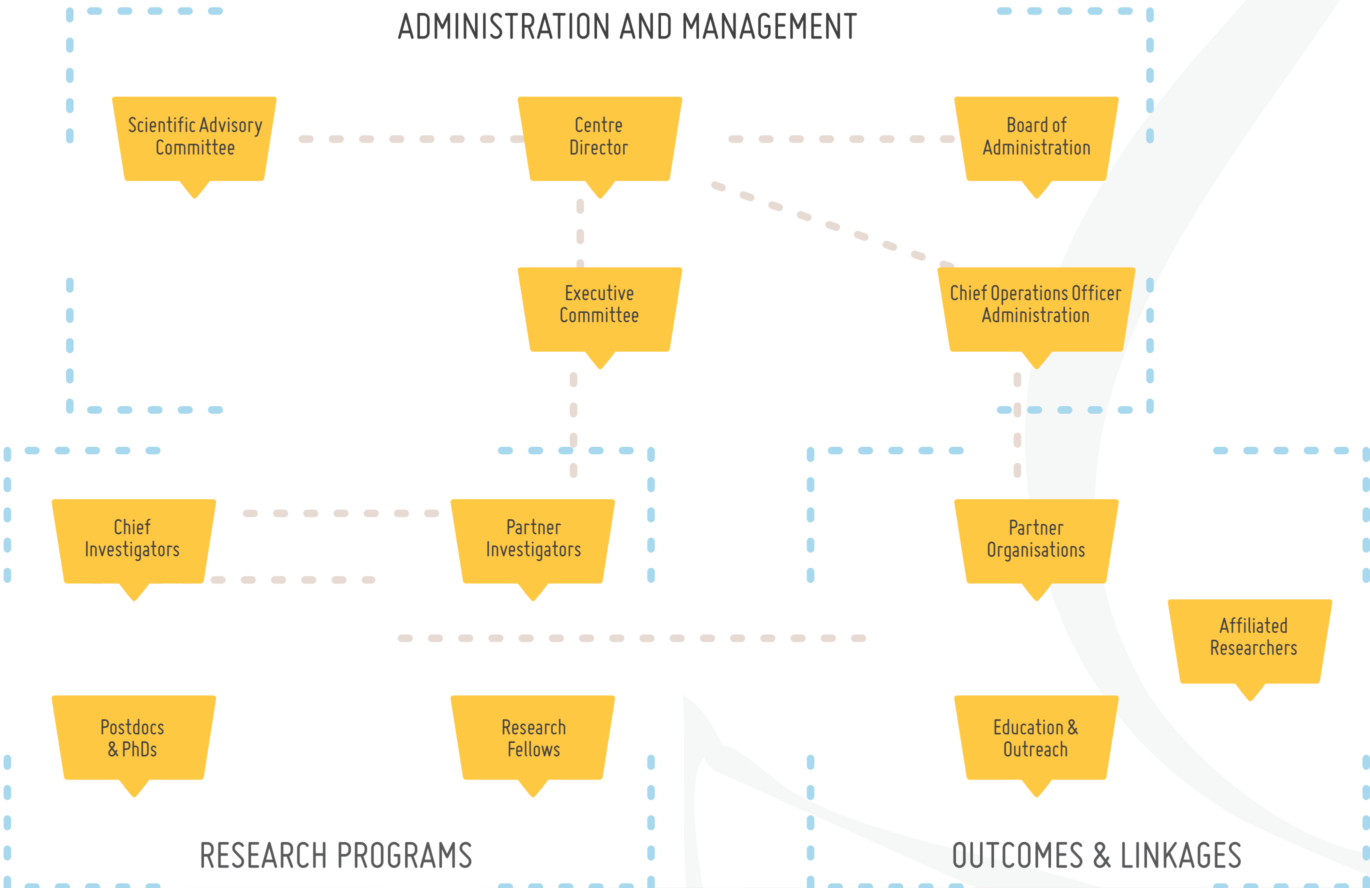
"Reactions can be triggered by rain drops falling, the wind blowing, an insect moving across a leaf or even by clouds casting a shadow over a plant" he said.

"Unlike animals, plants are unable to run away from harmful conditions. Instead, plants appear to have developed intricate stress defence systems to sense their environment and help them detect danger and respond appropriately."

ACROSS AUSTRALIA, A DEDICATED TEAM OF OUTSTANDING PEB RESEARCHERS ARE FOCUSED ON A BETTER UNDERSTANDING OF PLANT ENERGY SYSTEMS AND THE ENHANCEMENT OF PLANTS FOR OUR COLLECTIVE FUTURE.

People

ADMINISTRATION & MANAGEMENT



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 73 PhD, Masters and Honours students enrolled during 2016, 20 of whom commenced and 17 who successfully completed in the year. PEB students claimed a number of awards and authored numerous publications in 2016.

Student Highlight

John Rivers joined PEB in 2014 to commence his PhD studies into how plants make aroma and flavour chemicals. In addition to his strong intellectual interest in biochemistry John is passionate about agriculture, its long-term sustainability and the important role that plant science has to play in ensuring food security in the developing world.

John describes 2016 as a pivotal year when he developed an avid interest in the practical applications of science. Thinking about "how great ideas can be taken out of the lab and commercialised, or otherwise translated, into new products, jobs and programs that give back to society" led John to enter the 2016 Australia-France Entrepreneurship Challenge.

As part of the winning team he competed with other PhD students to come up with an innovative business idea and pitch it to potential investors. John claimed a study tour of innovation and entrepreneurship sites in France as the first prize.

"This challenge and tour broadened my perspectives about how my experience in a STEM PhD might be applied in the real world. There is much more work for people in France acting as mediators between academia and industry, for example. Now I know this job exists, it is what I want to do post-PhD: helping plant scientists to interact with industry and commercialise" he said.

John is grateful for the diverse experiences he has had in the Centre. Together with other Centre researchers he has authored a series of articles about plant genomics advances and opportunities for agriculture and conservation.

"I think our work has the greatest impact when we're working across disciplines and when we're aware of where our studies sit in the big picture".

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.

Affiliate Highlight

Dr Monika Murcha, an ARC Future Fellow and PEB Affiliated Researcher, completed her PhD studies with Professor Jim Whelan and subsequently worked as a PEB postdoctoral researcher before becoming an Independent Fellow in 2014. Monika has established a successful, affiliated research group and is passionate about deciphering the molecular mechanisms that regulate mitochondrial biogenesis underlying cellular activity, plant growth and responses to stress.

"When the opportunity arose to return to my passion of working with mitochondria, I jumped at the chance" she said. In 2016, Monika and her team published a paper in leading international journal Plant Physiology, detailing the first identification and characterization of a tRNA import component in plant mitochondria.

Monika states that being part of PEB has "provided me with access to outstanding research facilities, and integration into a vibrant and collaborative scientific community". Mentoring from those in the Centre has encouraged her to develop her own research interests and independence.

"As a Future Fellow my affiliation with the Centre has provided me with the support I needed to establish my own research laboratory, to deliver high-quality research publications, build my own team and attract independent funding."

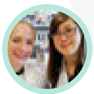
In turn, PEB has benefited from Monika's expertise in plant mitochondrial research, her recruitment of valuable new staff and students, and her ongoing involvement in PEB education and outreach activity.

Monika is a mother to three boys, aged 7 to 11. She hopes that her experience in successfully managing a career and a "big, boisterous family" will encourage young scientists. She quotes her colleague and friend Professor Christine Foyer, one of the world's most highly-cited plant scientists, in describing her experience as a scientist: *"Being passionate about science is what carries you through the hard times so that it isn't so much work as it is a hobby that you do for a living. It is the thrill of achieving a better understanding and finding real pleasure in putting new ideas together, explaining data and passing on knowledge that keeps you going no matter what".*

AWARDS & RECOGNITIONS

Andrew Scafaro	Marie Sklodowska-Curie Individual Fellowship	European Commission
Caitlin Byrt	Rana Munns Award	PEB, Grains Research & Development Corporation
Cornelia Hooper	Women's Young Investigator Travel Awards	The American Society of Plant Biologists
Diep Ganguly	Best Paper Prize	Australian Society of Plant Scientists
Diep Ganguly	2016 Award for a Program that Enhances Student Learning	The Australian National University Joint Colleges of Science
Estee Tee	2016 Award for Excellence in Tutoring or Demonstrating	The Australian National University Joint Colleges of Science
Estee Tee	2016 Award for a Program that Enhances Student Learning	The Australian National University Joint Colleges of Science
Estee Tee	Associate Fellow of the Higher Education Academy	Higher Education Academy
Ghislaine Platell	Homeward Bound Participant	Homeward Bound
Harvey Millar	Thomson Reuters 2016 Highly Cited Researcher	Thomson Reuters
Ian Small	Thomson Reuters 2016 Highly Cited Researcher	Thomson Reuters
Jayakumar Bose	The Daniel Walker Medal	The University of Adelaide
Jennifer Selinski	Feodor Lynen Fellowship	Humboldt Foundation
Jennifer Selinski	School of Life Sciences Publication Booster Award	La Trobe University
Jim Whelan	Thomson Reuters 2016 Highly Cited Researcher	Thomson Reuters
John Rivers	Australian-French Entrepreneurship Challenge Winner	Australian Academy of Science
Kai Xun Chan	2016 Award for a Program that Enhances Student Learning	The Australian National University Joint Colleges of Science
Kai Xun Chan	JG Crawford Award	Australian National University
Matthew Gilliham	Order of Merit	Executive Dean, Faculty of Sciences, University of Adelaide
Monika Murcha	2016 Rising Star Finalist	University of Western Australia Faculty of Science
Nicolas Tayor	Australia Japan Emerging Research Leaders Exchange Program	Australian Academy of Technological Sciences & Engineering
Olivier Van Aken	Western Australian Young Tall Poppy Award	Australian Institute for Policy and Science
Peter Crisp	2016 Award for a Program that Enhances Student Learning	The Australian National University Joint Colleges of Science
Peter Crisp	EMCR Travel Grant	The Australian National University
Ricarda Jost	School of Life Sciences Publication Booster Award	La Trobe University
Sandra Kerbler	Homeward Bound Participant	Homeward Bound
Stefanie Wege	Rana Munns Award	PEB, Grains Research & Development Corporation
Su Yin Phua	2016 Award for a Program that Enhances Student Learning	The Australian National University Joint Colleges of Science
Xin Hou	2016 Award for a Program that Enhances Student Learning	The Australian National University Joint Colleges of Science

PEB's team of exceptional researchers excel not only in their science but in their related endeavours. For this they are routinely recognised, and in 2016 PEB scientists were the recipients of a range of prestigious awards and recognitions.



Homeward Bound

In 2016, PEB PhD students **Sandra Kerbler** and **Ghislaine Platell** were selected as two of 76 female scientists from around the world to participate in the inaugural Homeward Bound initiative - an innovative, year-long leadership and strategy program for women in science, culminating in an expedition to Antarctica. Sandra and Ghislaine were selected for their passion about securing the future of the planet and a strong desire to play roles in solving the issue of gender inequality in science.

"I truly believe that with a greater representation of women at the leadership table, we can create change and develop a more sustainable future for all" said Sandra, who is investigating how plants adjust their metabolism in response to changing environmental conditions.

Ghislaine, a joint PhD student with PEB and the Centre for Integrative Bee Research (CIBER), is excited about the potential for science to make the world a better place. "I want to play a role in mitigating climate change, a monumental task that we can only achieve with collaboration and optimism" she said.

Both scientists felt that the program was valuable not only for their professional development, but for their personal development. Homeward Bound aims to equip a 1000-strong global collaboration of women with a science background with the ability to lead, influence and contribute to policy and decision making over the next 10 years. As Homeward Bound alumni Sandra and Ghislaine look forward to seeing the Homeward Bound initiative continue to develop and grow.

A Tall Poppy

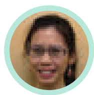
Dr Olivier Van Aken was named a 2016 Western Australian Young Tall Poppy in recognition of his outstanding work as a scientific researcher and communicator. His research focus is on plant responses to environmental stress. Olivier's work has led to the identification of several important genes that can help plants endure prolonged periods of drought, high salinity and microbial infections. He aims to develop strategies to translate improved plant stress responses from the lab to the field.

Olivier has shown an immense interest in communicating the importance of plant science to the wider community. He has been an active participant in many of PEB and UWA's science outreach activities, and in reaching out to the public to highlight the importance of plant science for everyday life.

The prestigious Tall Poppy awards are presented annually by the Australian Institute of Policy and Science (AIPS). *"Many Young Tall Poppies go on to achieve even greater things and become inspiring leaders in their field,"* said AIPS General Manager Camille Thomson.

Olivier's success as a researcher is reflected in the significant media attention given to his 2016 publication on plant touch responses, and on his appointment as an Associate Professor at Lund University, Sweden. He will establish his independent laboratory in 2017 to continue his valuable research into plant stress responses.

"It has been such a great experience to do my post-doctoral research at PEB, and it was the perfect platform to build my career. I am very happy with all the support and mentoring I received within PEB. The fact that many of our scientific works are receiving national and international media attention is a clear indication of the quality of research being done within PEB".



Excellence In Teaching

PhD student **Estee Tee** was inspired to pursue her research career by both the mentorship of PEB researchers during her undergraduate studies, who she says created an environment that encouraged her to realise her potential, and by a life-changing classroom experience with a Year 10 Science teacher who "saw the best" in her and turned science from a hated subject into a life's work.

Estee's experiences inspired her own passion for mentoring students, an activity she has been extensively recognised for. In 2016 Estee was made an Associate Fellow for the Higher Education Academy and presented with both the Award for Excellence in Tutoring or Demonstrating and an Award for a Program that Enhances Student Learning by the ANU College of Science.

Estee describes her extensive teaching activities as the most rewarding part of her PhD. *"I view my role as providing avenues and opportunities for my students. I strive to inspire and mentor them as my own wonderful teachers did for me."*

Estee teaches undergraduate students and regularly returns to her high school to present to young Science students and provide mentorship. She regularly participates in PEB's science outreach activity.

"Because of the previous and current great mentors I've had, as well as an incredibly supportive lab, I have been given wonderful opportunities to not only excel in science, but develop my skills in a number of areas such as teaching and science communication".

SCIENTIFIC ADVISORY COMMITTEE

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

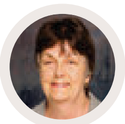
Emeritus Professor Dawes' research career has focused on the response of eukaryotic organisms to oxidative stress and ageing, the molecular analysis of control of one-carbon and folate metabolism in yeast and the mechanisms involved in initiation and timing of cell development. He is an editor of the 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	Affiliated Research Associate
Andrews	Jessica	Masters Student
Atif	Almalky	Masters Student
Baer	Boris	Affiliated ARC Future Fellow
Baer-Imhoof	Barbara	Affiliated Researcher, Outreach Officer
Bates	Tiffane	Affiliated Bee Yard Manager
Belt	Katharina	PhD Student
Bernath-Levin	Kalia	Affiliated Research Associate
Bogdanović	Ozren	Affiliated Researcher DECRA
Boykin	Laura	Affiliated Research Fellow
Brar	Kamalpreet	PhD Student
Broda	Martyna	PhD Student
Buckberry	Sam	Affiliated Postdoctoral Research Associate - ECR
Cahn	Jonathan	PhD Student
Castleden	Ian	Database/Systems Engineer
Chor	Yen Yeen	Masters Student
Cincu	Emilia	Graduate Research Assistant
Colas des Francs-Small	Catherine	Research Associate
Corral	Maxime	PhD Student
Cremen	Naomi	PhD Student
De Mendoza	Alex	Research Fellow EMBO
Dosselli	Ryan	Affiliated Research Associate
Du	Xianwen	Masters Student
Duffy	Ciara	PhD Student
Duncan	Owen	Affiliated Postdoctoral Researcher ECR
Elder	Katie	Masters Student
Farthing	Rosemarie	Laboratory Technician
Fenske	Ricarda	Research Officer
Fisher	Mark	PhD Student
Ford	Ethan	Research Associate
Franklin	Amy	PhD Student
Grassl	Julia	Affiliated Postdoctoral Research Associate
Gutmann	Bernard	Affiliated Researcher DECRA
Hall	Andrew	Honours Student
Haywood	Joel	Research Associate
Honkanen	Suvi	Research Associate - ECR
Hooper	Cornelia	Postdoctoral Researcher ECR
Howell	Kate	Affiliated Researcher DECRA
Huang	Shaobai	Affiliated ARC Future Fellow
Ivanova	Aneta	Affiliated Research Associate
Jeybalan	Jeya	Administration Officer
Karpievitch	Yuliya	Research Associate
Kerbler	Sandra	PhD Student
Khan	Adil	PhD Student
Kinene	Tonny	PhD student
Kratz	Madlen	PhD Student
Lee	Alex	Postdoctoral Researcher
Leroux	Julie	Research Assistant
Li	Lei	Affiliated Postdoctoral Researcher ECR
Lister	Ryan	Chief Investigator
Mann	Julia	PhD Student
Mcdowell	Rose	Masters Student
McLagan	Andrew	PhD Student
Melonek	Joanna	Research Fellow - ECR
Millar	Harvey	Director and Chief Investigator
Millman	Michael	PhD Student
Mohamed	Sufyaan	PhD Student
Moss	Dylan	Honours Student
Muhamad Hafiz	Che Othman	PhD Student
Munns	Rana	Chief Investigator
Murcha	Monika	Affiliated ARC Future Fellow
Mylne	Joshua	Affiliated ARC Future Fellow
Ng	Sophia	Affiliated Postdoctoral Researcher ECR
O'Leary	Brendan	Affiliated Researcher DECRA
Oliva	Marina	Postdoctoral Researcher ECR
Palanivelu	Nithya	PhD Student

Petereit	Jakob	PhD Student
Pflueger	Christian	Postdoctoral Researcher ECR
Poppe	Daniel	Research Associate
Porri	Aimone	Research Fellow EMBO
Pouvreau	Benjamin	PhD Student
Price	Karina	Science Communications Officer
Pruzinska	Adriana	Affiliated Researcher DECRA
Rudler	Danielle	Honours Student
Salih	Karzan	PhD Student
Secco	David	Affiliated Researcher DECRA
Shute	Geetha	Chief Operations Officer
Simmons	Rebecca	PhD student
Small	Ian	Chief Investigator
Small	Ghislaine	PhD Student
Ströher	Elke	Research Fellow
Stuart	Tim	PhD Student
Sun	Kelly	PhD Student
Tan	Dennis	PhD Student
Tang	Ting	Graduate Research Assistant
Tang	Anqiang	Masters Student
Tanz	Sandra	Affiliated Researcher DECRA
Taylor	Nicolas	Affiliated ARC Future Fellow
Tonti-Filippini	Julian	Affiliated Research Associate
Troesch	Josua	Technical Officer
Vacher	Michael	Research Associate - ECR
Van Aken	Olivier	Affiliated Research Fellow
Van der Merwe	Margaretha (Marna)	Affiliated Researcher DECRA
Vargas Landin	Dulce Beatriz	PhD Student
Vincis Pereira Sanglard	Lilian Maria	PhD Student
Wainaina	James	PhD student
Walker	Hayden	IT Officer
Wallace	Michael	Honours Student
Ward	Katherine	Purchasing/Accounts Officer
Waters	Mark	Affiliated Future Fellow
Zhong	Xiao	PhD Student

AUSTRALIAN NATIONAL UNIVERSITY

Abdul Bahar	Nur	PhD Student
Ahmad Rashid	Fatimah Azzahra	PhD Student
Alves Negrini	Ana Clarissa	Postdoctoral Researcher ECR
Asao	Shinichi	Research Fellow
Atkin	Owen	Chief Investigator
Borevitz	Justin	Chief Investigator
Bowerman	Andrew	Research Associate ECR
Brown	Tim	Affiliated Research Fellow
Chan	Kai Xun	Postdoctoral Researcher ECR
Cheng	Riyan	Postdoctoral Researcher ECR
Coast	Onoriode	Research Associate
Collinge	Derek	Lab Manager
Crisp	Peter	Postdoctoral Researcher ECR
Cullerne	Darren	Research Associate
Dunstan	Gareth	Technician
Eichten	Steven	Affiliated Researcher DECRA
Fan	Yuzhen	Technical Officer
Gaju	Reshmi	Research Associate
Ganguly	Diep	PhD Student
Hayes	Lucy	Technical Assistant
Heussler	Alison	Technical Officer
Hocking	Bradleigh	PhD Student
Hou	Xin	PhD student
Kariyawasam	Buddhima	PhD student
McQuinn	Ryan	Postdoctoral Researcher ECR
Murray	Kevin	PhD Student
Nisar	Nazia	Affiliated Postdoctoral Researcher
Phua	Su Yin	Senior Technical Officer
Pogson	Barry	Deputy Director and Chief Investigator

AUSTRALIAN NATIONAL UNIVERSITY (CON'T)

Rivers	John	PhD student
Rungrat	Tepsuda	PhD student
Scafaro	Andrew	Postdoctoral Researcher ECR
Shah	Shahen	Divisional Visitor
Smith	Aaron	Honours student
Spence	Matthew	Technical Officer
Streich	Jared	PhD student
Supple	Megan	Postdoctoral Researcher ECR
Taghavi-Namin	Sarah	Research Associate
Tee	Estee	PhD Student
Tucker	Josephine	Technical Officer
Warthmann	Norman	Postdoctoral Researcher ECR
Watkins	Jacinta	PhD Student
Wilson	Phillipa	Postdoctoral Fellow
Worcester	Corey	Operations Manager
Xiang	Jen	Honours student
Xiong	Xiaofeng	PhD student
Yadav	Arun	Affiliated Postdoctoral Researcher ECR
Zhang	You	Honours Student
Zhu	Lingling	PhD student

UNIVERSITY OF ADELAIDE

Bose	Jayakumar	Postdoctoral Researcher
Byrt	Caitlin	Affiliated Researcher DECRA
David	Rakesh	Affiliate Researcher - ANDS - ECR
Feng	Xueying	PhD student
Gilliham	Matthew	Chief Investigator
Henderson	Sam	Postdoctoral Researcher ECR
Kamran	Muhammad	PhD Student
Long	Yu	Research Fellow
Mafakheri	Ali	Research Assistant
McGaughey	Samantha	PhD student
Qiu	Jiaen	Postdoctoral Researcher ECR
Qu	Yue	PhD Student
Ramesh	Sunita	Postdoctoral Research Associate
Scharwies	Johannes	PhD Student
Shelden	Megan	Affiliated Researcher DECRA
Sullivan	Wendy	Lab Manager
Tyerman	Stephen	Chief Investigator
Vandeleur	Rebecca	Operations and Research Manager
Wang	Chuang	Postdoctoral Research Associate - ECR
Watts-Williams	Stephanie	Affiliated Research Fellow -ECR
Wege	Stefanie	Affiliated Researcher DECRA- ECR
Wignes	Jonathan	PhD Student
Wu	Yue	PhD Student
Xu	Bo	Postdoctoral Fellow - ECR

LA TROBE UNIVERSITY

Berkowitz	Oliver	Research Fellow
Jost	Ricarda	Research Fellow
Linn	Joshua	PhD student
Lu	Li	PhD student
Lyu	Wenhui	PhD Student
Meng	Xiangxiang	PhD Student
Narsai	Reena	Research Fellow
Osorio	Marina Borges	PhD Student
Ren	Meiyan	PhD Student
Wang	Yan	Research Fellow
Whelan	Jim	Chief Investigator
Zanganeh	Fatemeh	PhD Student
Zhang	Botao	Research Fellow - ECR

2016 Publication Fast Facts

- Total number of publications by Centre staff: 117
- Average impact factor: 6.42
- Publications in top journals (impact factor 10 and above): 14
- Top Journals include Nature Genetics, Nature Communications, Genome Research, PNAS, Plant Cell and eLife.

Alexova R, Nelson CJ, Millar AH (2016) Temporal development of the barley leaf metabolic response to Pi limitation. PLANT, CELL AND ENVIRONMENT DOI: 10.1111/pce.12882.

Amarasinghe S, Watson-Haigh NS, Gilliham M, Roy S, Baumann U (2016) The evolutionary origin of *CIPK16*: A gene involved in enhanced salt tolerance. MOLECULAR PHYLOGENETICS AND EVOLUTION 100:135-47.

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Atkin O (2016) New Phytologist: bridging the 'plant function - climate modelling divide'. NEW PHYTOLOGIST 209(4):1329-32.

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Bahar NH, Ishida FY, Weerasinghe LK, Guerrieri R, O'Sullivan OS, Bloomfield KJ, Asner GP, Martin RE, Lloyd J, Malhi Y, Phillips OL, Meir P, Salinas N, Cosio EG, Domingues TF, Quesada CA, Sinca F, Escudero Vega A, Zuloaga Ccorimanya PP, Del Aguila-Pasquel J, Quispe Huaypar K, Cuba Torres I, Butrón Loayza R, Pelaez Tapia Y, Huaman Ovalle J, Long BM, Evans JR, Atkin OK (2016) Leaf-level photosynthetic capacity in lowland Amazonian and high-elevation Andean tropical moist forests of Peru. NEW PHYTOLOGIST DOI: 10.1111/nph.14079.

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Bogdanović O, Smits AH, de la Calle Mustienes E, Tena JJ, Ford E, Williams R, Senanayake U, Schultz MD, Hontelez S, van Kruijsbergen I, Rayon T, Gnerlich F, Carell T, Veenstra GJ, Manzanares M, Sauka-Spengler T, Ecker JR, Vermeulen M, Gómez-Skarmeta JL, Lister R (2016) Active DNA demethylation at enhancers during the vertebrate phylotypic period. NATURE GENETICS 48(4):417-26.

Bogdanović O, van Heeringen SJ (2016) ChIP-seq Data Processing for PcG Proteins and Associated Histone Modifications. METHODS IN MOLECULAR BIOLOGY 1480:37-53.

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Fax: 61 8 6488 4401

Australian National University
Research School of Biology
Linnaeus Building, Building 134
Linnaeus Way, Acton, 0200 ACT
Phone: 61 2 6125 3741
Fax: 61 2 6125 5075

THE UNIVERSITY of ADELAIDE
School of Agriculture Food and Wine
Waite Campus
Private Mail Bag 1, Glen Osmond, 5064 SA
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