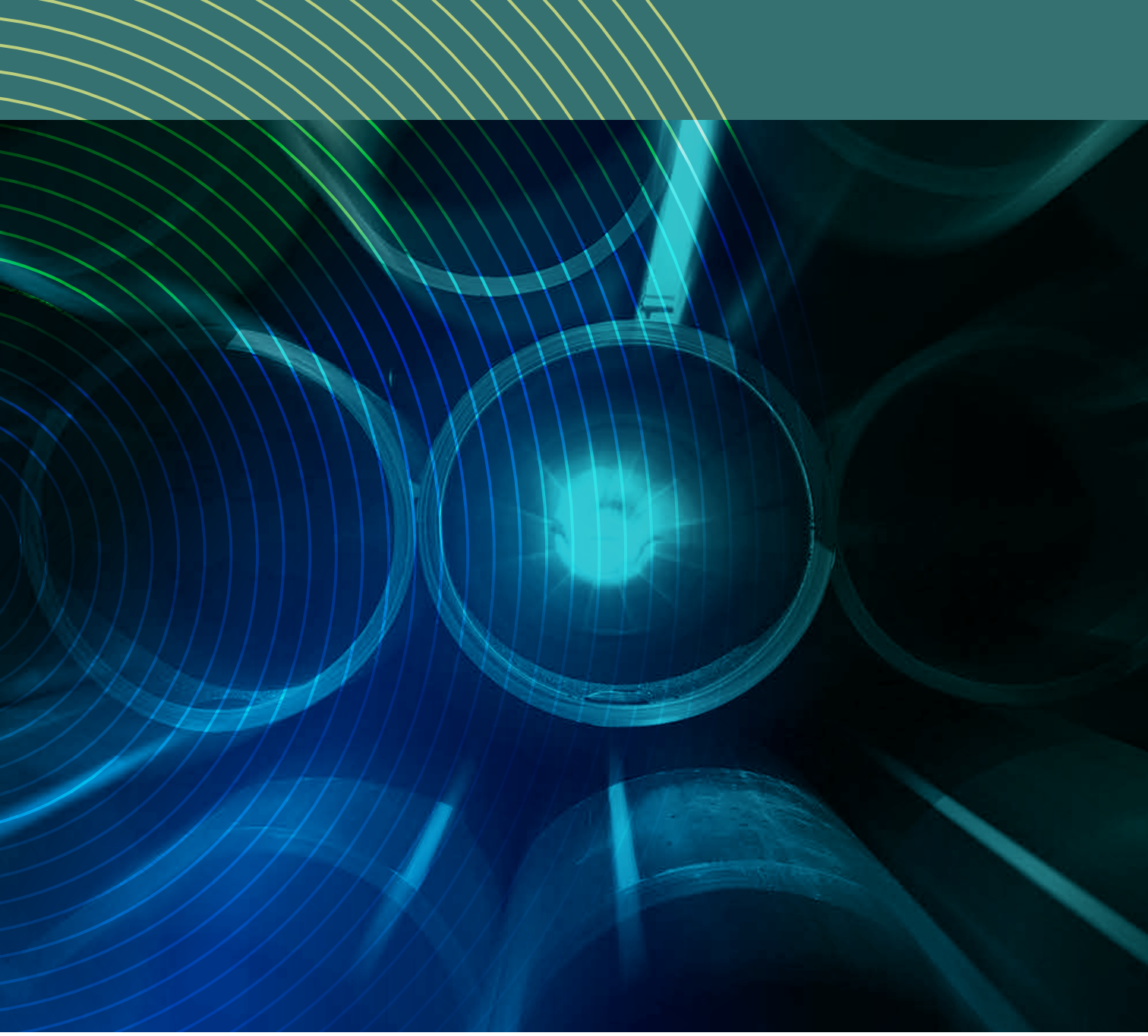
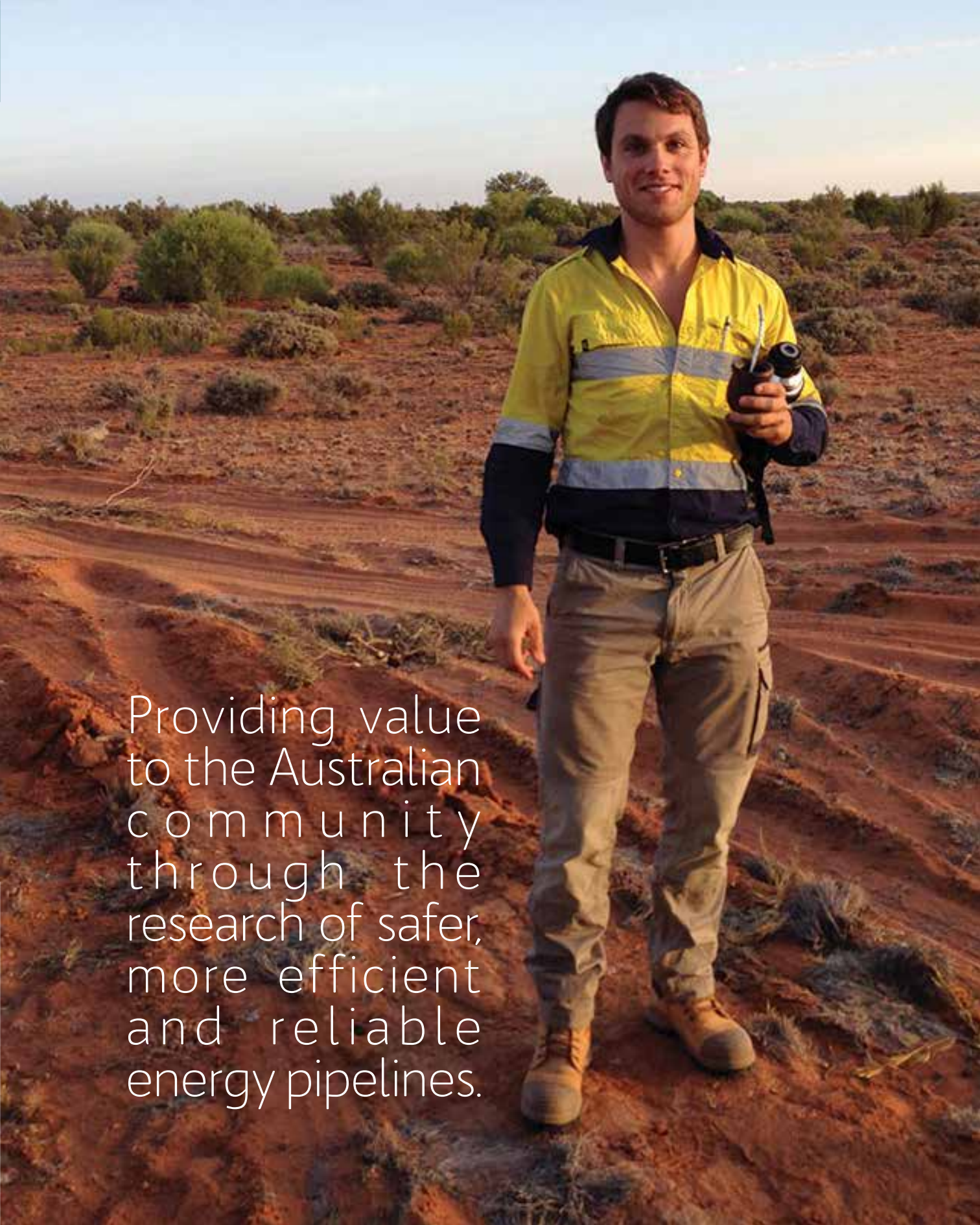


ENERGY Pipelines CRC



Providing value to the Australian community through the research of safer, more efficient and reliable energy pipelines.

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Foreword

Valerie Linton, Executive Dean Faculty of Engineering and Information Sciences, University of Wollongong.

It gives me great pleasure to be invited to write this foreword for the Energy Pipelines CRC legacy book. From its beginnings as an idea in Leigh Fletcher's mind to its successful conclusion after 10 years of operation, the Energy Pipelines CRC has played a meaningful role in the energy pipelines sector and interacted with many industry professionals and researchers both in Australia and overseas.

Cooperative Research Centres are established to address issues of critical Australian national interest and the Commonwealth government provides funding to cooperations of industry, researchers and other relevant parties to come together to solve these issues.

The Energy Pipelines CRC has been held up by the Commonwealth Government as a stand out example of an industry led CRC that worked in a focused way to deliver solutions in a form that industry could take and adopt. This included the topics within the Energy Pipelines CRC's initial remit and across many other areas as engagement and opportunities grew. That so much of the work of the Energy Pipelines CRC ended up in Standards and industry guidelines speaks to the relevance of the outcomes.

CRCs are also training grounds for the next generation of young professionals, and Energy Pipelines CRC was no exception with almost all of its PhD and masters students taking up employment in the industry or continuing pipeline related research on completion of their studies.

The success of the Energy Pipelines CRC was dependent on the hard work and dedication of many individuals across all of the partners and the industry. I would like to acknowledge and thank all of those who have played their part in the success of the Energy Pipelines CRC. You can be proud of the achievements summarised in this book.

Chairman's Note

Charles Rottier, Chairman

The Energy Pipelines CRC was established in 2009 with the clear vision of enabling safer, more efficient and reliable pipelines to meet Australia's growing energy needs. This was the challenge set by the Australian pipeline industry as we entered a new decade in which Australian reliance on gas and water infrastructure had grown significantly.

Over its 10 year life, the Energy Pipelines CRC has facilitated research across a broad spectrum of disciplines, including materials, coatings, design and examination of public safety and security of supply, to deliver outcomes necessary for the continued strength of the Australian pipeline industry. These outcomes have cemented the legacy of the organisation as an effective CRC.

The management team have played a key role in the success of Energy Pipelines CRC. Under the leadership of CEOs Valerie Linton (foundation), David Norman and Robert Newton, the team has shown the commitment and passion necessary to manage the research activities and delivery of outcomes.

The past and present members of the Board have provided valuable guidance and direction throughout the years in respect to the activities of the CRC. I would like to pay special tribute to the foundation Board Chairman Jim McDonald for his dedication to the establishment and success of the Energy Pipelines CRC.

The continued support and engagement from the Australian pipeline industry, in particular the APGA Research and Standards Committee, is gratefully acknowledged. The knowledge and dedication evident within this group has helped drive the Energy Pipelines CRC research outcomes towards tangible results that have a continuing direct impact on industry.

Finally, I wish to acknowledge the support of the Australian Government through its Cooperative Research Centres Program. The funding provided through the Program has greatly assisted the Energy Pipelines CRC to achieve its desired outcomes.

Background

> The Energy Pipelines CRC enriched the research life of my Faculty by making research attractive and challenging to young researchers, students and mid-career staff, ensuring a supply of excellent expertise to Industry
>
> **Chris Cook, Former Dean of the EIS Faculty, University of Wollongong and Energy Pipelines CRC Director.**

The Energy Pipelines CRC (EPCRC) was established in 2009 to facilitate collaboration between researchers and the energy pipeline industry sector in Australia. The goal was to provide the Australian energy pipeline industry with the knowledge and technology necessary to extend the life of the existing natural gas transmission network, and to build better, cost effective and safer networks necessary to support increasing demand for energy.

Strong management and industry engagement have allowed the company to adjust its research activities to meet changing industry needs. The cessation of Australian line pipe manufacturing in 2012 required a quick refocus of priorities across research activities. High levels of industry consultation and engagement have been evident throughout all research projects in the Energy Pipelines CRC delivering outcomes that can be directly adopted by industry and providing maximum value.

The Energy Pipelines CRC was supported by a combined $27.480 million from the Commonwealth and industry as well over $60 million in kind contributions from Universities and industry.

The Energy Pipelines CRC has remained true to its vision. Its legacy will have long lasting impact in the day to day operations of the Australian pipeline industry.

Major Program Highlights

100+

projects undertaken in four main research programs

280+

research reports and industry guidelines directly benefitting the Australian pipeline industry

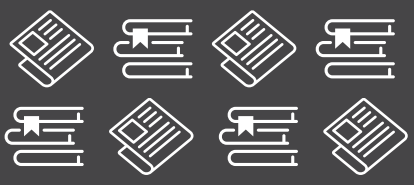
Outcomes disseminated through:

200

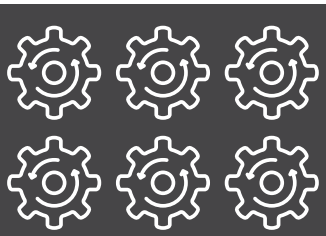
national and international industry conference and seminar presentations

250+

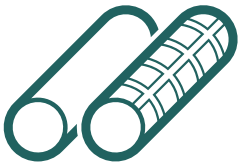
publications in academic journals have been published worldwide



Substantial input into updates to Australian industry Standards, in particular the Australian pipeline industry standard AS2885



New pipeline design models and software developed and implemented, including for fracture control and gas dispersion



NEW DEVICES AND TECHNOLOGIES DEVELOPED, INCLUDING:

Corrosion protection survey system

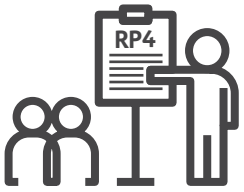
Coating and CP survey tool for HDD pipes

Prediction-based decision support framework for energy pipeline integrity management

Establishment of the National Facility for Pipeline Coating Assessment at Deakin University

Informed by program 4 'Public Safety and Security of Supply' research outcomes; a new part of AS2885 was developed to cover safety management

Industry process safety awareness enhanced through industry engagement with program 4 researchers



Exceeded budgeted staff in-kind levels and non-staff in-kind levels

25 higher degree research students

AND

57 research fellows/ postdoctoral researchers

were actively involved in facilitating transfer of knowledge between industry and academia as a direct result of the Energy Pipelines CRC research activities

80+

industry advisors regularly provided a significant portion of their time to guide and manage the research

Expertise gained has been utilised in other non-CRC funded activities; in particular delivery of projects related to CO_2 pipelines research

Research Outcomes

Research Program 1

RP1

More efficient use of materials

The program aimed to support lower cost pipe construction and life extension of energy pipelines by using materials more efficiently and avoiding material-related problems. The four major research areas were weldability of pipeline steels, high strength steels, linepipe properties and specification, and polyethylene (PE) pipes.

Weldability of pipeline steel

Welding issues on new and existing pipelines are a constant challenge for the Australian pipeline industry. University of Wollongong researchers in collaboration with ANSTO investigated different thickness limits prescribed in industry Standards for which post weld heat treatment (PWHT) is required, and considered elimination of PWHT in cases of the absence of Hydrogen Assisted Cold Cracking (HACC). The results informed Australian pipeline Standard AS 2885 Part 2 'Welding', and aim to reduce costs for pipeline operators associated with the elimination of unnecessary PWHT.

As part of a separate research program undertaken by the University of Adelaide and the University of Wollongong, industry guidelines were developed for predicting and controlling weld metal HACC.

In 2013, the Energy Pipelines CRC collated impartial information on available commercial mechanised gas metal arc welding (GMAW) girth welding systems, different welding process options and also objectively compared the potential productivity of the systems. Any company that is constructing large diameter pipelines in Australia still benefits from this.

High strength steel

The use of higher strength steels was addressed by investigating methods of manufacture, specification, joining and repair. The outcomes provided a basis for systematic evaluation of risks and mitigation strategies for the use of X80 grade pipe in Australian applications.

Research in this area also included the investigation of the effect of the titanium:nitrogen ratio on the Heat Affected Zone (HAZ) toughness, which led to recommendations in regards to optimum linepipe steel composition. In turn, this informed the development of an Australian industry specification for linepipe.

Linepipe specification

Following the cessation of the Australian linepipe manufacturing industry in 2012, a key challenge for Australian constructors was having confidence in dealing with international suppliers. A 'Linepipe specification' was developed to assist the Australian pipeline industry to purchase overseas linepipe with greater confidence.

The research addressed the adequacy of current Australian, ISO and API standards for the specification of purchased overseas linepipe and provided the specification of high frequency welded (HFW) and longitudinal-submerged arc-welded (LSAW) pipes for gas transmission application in sizes up to DN650. The research outcomes were adopted in the design part (Part 1) of AS 2885.

Polyethylene (PE) Pipes

Significant research in polyethylene (PE) pipes, supported by members of the Energy Pipelines CRC Plastic and Composite Pipe User Group, increased the understanding of PE pipe degradation mechanisms. Specifically, it produced a new standardised approach for assessing the relative remaining lifetime of PE pipes that includes material grade, pipe location and age.

The suitability of this approach has also been assessed for other plastic pipe materials used in the gas network and has allowed gas distribution network owners and operators to optimise the replacement and repair programs of gas mains.

The specification avoids the need to develop new supplementary linepipe specifications for many new pipeline projects, leading to significant cost savings.

A number of industry advisors involved in the Energy Pipelines CRC

Research Program 2

RP2

Life extension of new and existing pipelines

Research outcomes have supported the cost effective extension of pipeline operating life by mitigating the corrosion and environmentally assisted degradation of pipelines. Industry challenges were addressed in three main areas: coatings and cathodic protection (CP), asset life prediction and management and stress corrosion cracking (SCC).

Coatings and Cathodic Protection

Research targeted two major failure mechanisms of energy pipeline coatings: cracking of coatings under mechanical strain during hydrostatic testing or pipe bending, and disbondment of coatings under excessively negative cathodic protection voltage. This resulted in a new technique for in-situ evaluation and monitoring of cathodic disbondment based on electrochemical impedance measurement by means of a multi-electrode array. This technique overcomes the limitations of existing laboratory practices, and will improve asset management practices.

The research was supported by the National Facility for Pipeline Coating Assessment (NFPCA) established at Deakin University with funding from Energy Pipelines CRC. The success of the NFPCA was recognised with an Excellence in Innovation Award from the Cooperative Research Centres Association (CRCA) in 2016.

Research on High voltage holiday testing of Dual Layer Fusion Bonded Epoxy (DLFBE) coatings. provided guidelines on the critical voltage value for holiday testing of DLFBE. This provided input to the Australian Standard AS 3662: External fusion-bonded epoxy coating for steel pipes.

Asset Life Prediction and Management

Research revealed that CP potential excursions such as those caused by train and tram lines do not necessarily cause pipeline corrosion, as long as their amplitude and duration are below the critical values. These findings have been considered for inclusion in AS 2832.1 'Cathodic protection of metals' .Inclusion of this research in the Standard supports CP management practices and saves costs for the pipeline operators.

Other projects undertaken provided engineering guidance for the design and operation of CP systems at pipeline shoreline crossings. The project quantified the effects of impressed current CP systems on galvanic anode systems for both new and existing pipelines. This research resulted in an industry guideline to optimise the design of CP systems for offshore pipelines coming to shore and connecting to onshore pipeline systems and has been adopted in both Australian and international Standards.

Activities complemented the work on coatings and cathodic protection focussing on the development of improved pipeline condition monitoring (PCM) systems and sensors.

The research reviewed, evaluated and verified a number of technologies potentially suitable for monitoring of pipeline integrity at critical pipeline sections. This led to the design of two new sensors / probes by Deakin researchers. The first sensor can monitor three major 'worst-case scenario' pipeline safety and durability hazards: CP excursions due to stray current influences, cathodic disbondment of pipeline coatings, and corrosion under disbonded coatings. The sensor has been tested in the field on a number of locations in Victoria and forms the basis for new commercial integrity solutions. The second sensor can be used for detecting the location and size of coating defects, as well as CP efficiency at such defects, under HDD pipeline conditions.

Stress Corrosion Cracking

This research has provided industry with a greater understanding of the mechanisms for Stress Corrosion Cracking (SCC) initiation and growth, and ultimately with more effective SCC assessment and management tools.

This research provided valuable insight into the SCC cracking phenomena and particularly the angled cracking, providing a clear explanation of the mechanism for the formation and growth of angled cracks and thereby providing confidence in SCC assessment tools used in Industry.

Such SCC assessment tools are also informed by research that determined pipe manufacturing processes leading to an increased susceptibility to SCC in pipeline assets, as well as investigations into the role of pipe wall surface finish and contaminants in the development of conditions that enable the initiation of SCC.

Research Program 3

RP3

Advanced design and construction

Research value was demonstrated through recommended improvements in the design and construction related factors in Australian pipelines that affect cost, reliability and safety. This program included three main areas of fracture control, advanced pipeline design and construction, and future energy fluids and was heavily supported by industry advisors from major engineering firms, construction companies and pipeline owners.

Fracture Control

Fracture control has been one of the Energy Pipelines CRC flagship research areas, with strong international recognition.

Researchers at the University of Wollongong focussed on:

- New methods for fracture control in small diameter natural gas and other energy fluid pipelines;
- Accurate numerical models of Fluid-Structure Interaction (FSI) during running ductile fracture as an alternative to full-scale testing; and
- New improved fracture velocity model that incorporates the effect of the material ductility (Y/T ratio) on the fracture propagation velocity.

The EPDECOM fracture arrest software was one of the significant outcomes of this research. EPDECOM is a modern fracture control application for the control of running ductile fracture integrating a gas decompression model and a fracture propagation model to estimate the minimum required toughness based on the Battelle Two-Curve Method.

A number of industry advisors involved in the work described this internationally acclaimed research as extremely valuable to industry:

"Fracture Control is a key technical requirement of AS 2885.1 because it underlies the safety of high pressure gas pipelines. The Standard is (and will continue) to recognise significant fracture control developments from this research program."

Pipeline Design and Construction

Researchers assessed the suitability of commonly used transient hydraulic models to predict the pipe metal temperatures during gas venting operations. This has provided an opportunity for pipeline design houses to use the latest research for optimal design of pipeline vent stacks thereby reducing construction costs.

Key issues such as ignition of flammable gas, dispersion of gas, and noise levels arising from the installation and operation of vents attached to a high pressure gas pipeline were also addressed resulting in an industry guideline to determine the design, placement and operation of vents for new or augmented pipelines in both rural and urban locations.

A number of other design guidelines and models focussed on specific aspects of pipeline design, construction and operation have been prepared from the research outcomes. These have included:

- Direct industry guidance on the strain demand thresholds during pipeline construction activities to prevent coating damage;
- A scientific basis for removing a constraint that prevents certain Australian pipelines from increasing their operating pressure (up to 15%) once it is demonstrated that the increase in operating pressure is safe;
- Numerical models to understand horizontal directional drilling damage to pipelines so that pipeline engineers doing safety management studies can make valid assessments of the risk presented by such equipment.
- Field pressure test modelling software PipeStrain has been developed and significantly improved by the Energy Pipelines CRC.
- In light of investigations into drop weight tear testing (DWTT) for smaller diameter pipelines, both AS2885 and the Australian DWTT test standard are modified to embrace project findings.
- Practical geotechnical guidelines for the industry in relation to two geotechnical issues, i.e. soil restraint against buoyancy forces and the loads on pipe due to vibratory compaction.

Future Energy Fluids

This program considered future energy needs and focussed on pipelines transporting new energy fluids such as hydrogen, syngas, ammonia etc. This provided industry with a modelling tool that allows for assessment of the economic viability of transporting new energy fluids by pipeline.

Research helped to quantify the opportunities associated with gases such as synthesised natural gas, batch or blend options in natural gas pipelines, as well as synthetic liquid fuels. A "traffic light" methodology has been developed that is capable of screening a large number of potential pipeline energy fluids based on a number of techno-economic criteria. This supported the pipeline companies to better position themselves in potential future markets for new energy fluids.

Research Program 4

RP4

Public safety and security of supply of energy pipelines

Research activities within program 4 have supported the goal to sustain the world's best practice safety and reliability performance of Australian energy pipelines that are under threat from ageing of the network, deskilling of the industry, and population encroachment on pipelines in formerly rural locations. The program complemented the three technical programs and analysed the human and organisational dimensions in the operation of, and interaction with, pipelines. Industry education was an integral part. The social and organisational factors were addressed in effective safety regulation, organisational safety, and pipelines in the community.

Effective Safety Regulation

Research aimed to improve safety and reliability of pipelines by more focussed regulatory activity and reduced overall regulatory compliance costs for industry as activities are better targeted. The differing views and priorities of safety regulators in hazardous industries from a sociological perspective were explored.

The reports and seminars have supported competent, independent and engaged safety regulators in the high pressure pipeline industry through:

- A review most commonly used high reliability organisation (HRO) self-assessment tools for improving the process safety performance of the pipeline sector companies;
- Research into the influence of economic regulation on the long term integrity of gas networks in Australia; and
- Review of regulation and regulatory practice across the Australian States and clear recommendations in order to provide more effective regulatory oversight.

Regulators were involved through the RP4 Steering Committee and the regulators' forum. The regulators have been updated on research of relevance to the general public, hence working in the best interest of all Australian communities.

Organisational Safety

The reputation of the RP4 research into organisational causes of accidents is world renowned, with RP4 program leader A/Prof. Jan Hayes providing lectures at major international conferences.

Research increased awareness and understanding of organisational causes of pipeline accidents that occurred overseas or in other sectors, reducing the risk of similar problems in the Australian pipeline sector.

Research into organisational safety informed the update process of several parts of AS 2885.1, including risk communication, high-consequence risk assessment and accountability.

New part 6 of the Australian pipeline Standard, AS 2885 - Safety Management - includes more specific requirements for safety management studies and draws upon the RP4 research, in particular:

- Providing support for professional engineering judgements made regarding risk acceptability in accordance with the principle of As Low As Reasonably Practicable (ALARP);
- Improving guidance for communicating with third parties who intend to work around pipelines (and may damage them); and
- Improving communication to senior management regarding the potential consequences of pipeline failure and the impact of management decisions.

Two books focussing on organisational safety- 'Nightmare pipeline failures: fantasy planning, black swans and integrity management' (Jan Hayes and Andrew Hopkins) and 'Risky Rewards: How company bonuses affect safety' (Andrew Hopkins and Sarah Maslen) have been published.

> The sociological approach of RP4 was truly innovative in the global pipeline industry. The change in attitude is perhaps best illustrated by the late cancellation of Jan Hayes' paper for the International Pipeline Conference as "not relevant" followed by the invitation to Jan to be keynote speaker at the next conference two years later.
>
> **Peter Tuft, Industry Legend**

Pipelines in the community

The research aimed to reduce the potential damage to pipelines in the community by more effective controls on surrounding land use, as well as improved awareness and work practices for those around pipelines.

Research provided a number of strategies for reducing the risk of third party interference with pipelines and investigated the views and priorities of stakeholders involved in planning and decision making for residential land use and urban development in proximity to existing pipelines.

Case study work compared land use planning practices around pipelines in the UK with those in Victoria and South Australia. This provided direction to consider how Australian land use planning arrangements could be improved in assessing the impact of high pressure pipelines.

Through collaborative industry – researcher workshops, a range of engineering and procedural controls used in AS 2885 to protect pipelines from external interference were reviewed, and also identified new controls which may be beneficial for inclusion in the standard or further R&D.

One industry advisor commented: *"the practical application of research program 4 in the industry is wide-spread, ranging from changing the way our risk assessments are done, through to greater awareness about the safety implications when subcontracting excavation work."*

My experience with the EPCRC has been an overwhelmingly positive and enjoyable one for me. It has also been gratifying for me to see the increased collaboration between the industry personnel and the universities' staff and the lessons learned from both sides.

Steve Dobbie, Board Director

Research Value

In order to independently assess and where possibly quantify, the value the Energy Pipelines CRC to industry, ACIL Allen Consulting completed a comprehensive study on the economic impacts of the CRC's research programs.

This study clearly demonstrated that the primary rationale for the Energy Pipelines CRC — to deliver high quality, industry-ready pipeline research that is practical and commercially valuable — has been delivered. The value of research outcomes are conservatively seen to be well in excess of the costs of research.

A good example of the value of the research relates to fibreglass bonded epoxy repairs. The manufacturers were telling us that they're suitable for use [in remediating stress corrosion cracking problems] but the research showed conclusively that they did not perform adequately under fatigue testing. So in this case the saving was more about not making a mistake by installing an inappropriate treatment and having to replace it down the track.

The industry benefits of successful research that this study captured can be broadly grouped into four classes:

1

Reduced capital costs:

lowering construction costs; more efficient and effective pipeline design

2

Reduced operating and maintenance costs:

lowering ongoing costs of pipeline operations through more effective asset monitoring, protection and maintenance planning

3

Asset optimisation:

enhancing the capability of existing pipelines through capacity expansion and life extension, thereby allowing deferral of expenditure on expansion and replacement of assets

4

Improved safety performance:

reducing the risk of pipeline failures and their potential adverse consequences in terms of public safety, environmental damage/threats, economic and commercial loss and industry reputational damage

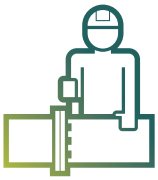
The Energy Pipelines CRC was seen as filling a major gap in pipelines research capability that had emerged in the post-privatisation era:

There are some aspects that have had some really good results; some others that haven't quite delivered the results that we were maybe hoping for. That's not necessarily the fault of the CRC itself but more the nature of the sort of research which has, in those cases, led perhaps to a lot more questions than answers. But on the whole it's been really valuable. Going back to days prior to the privatisation of the energy industry in Victoria a lot research was done, and was shared with other government organisations and also with the larger interstate gas companies. Before the Energy Pipelines CRC was established, that had all disappeared. Not a great deal was being done and there was a lot of reliance on what suppliers were providing. Contractors would rely on information from overseas that was being taken at face value without work being done to validate what we were being told. So the value of the CRC being there, from my point of view, is in being able to do research focused on some particular Australian issues and also as our facility for quality checking and failure investigations that would otherwise be very difficult to undertake in Australia. There are really no other options that open without going offshore.

The net benefits of the Energy Pipelines CRC research program measured according to a formalised benefit–cost methodology that is also used by the Commonwealth Government to assess the impact of CRC programs have increased significantly over time.

ACIL Allen concluded that benefits exceeded costs by a factor of 4.5. This result remains robustly positive even when higher discount rates, that are more reflective of commercial costs of capital, are applied to the discounted cash flow analysis.

The CRC's value has come about largely as a result of both research success and industry uptake of research. These outcomes have been demonstrated by completed projects and by uptake of results, for example into the overarching industry standard for pipelines AS 2885. Examples of such outcomes include:

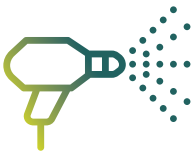


Fracture control in pipelines

Research undertaken at the University of Wollongong has made very significant progress in the understanding and control of fracture in pipelines. This work encompasses pipeline decompression and the influence of pipe roughness and diameter, fracture mechanism, toughness requirements for fracture arrest and the measurement of toughness in DWTT and Charpy tests. The work has resulted in new recommended practices for performing DWTT and EPDECOM, a commercially available decompression/arrest toughness software package.

Sociology of safety

The work being undertaken by the RMIT research team has raised serious interest in how the structure and culture of companies directly affect the safety of their assets. The work has led to a number of changes to the safety management provisions in AS2885.1 and the creation of AS2885.6 'Safety Management'.



Coatings and Cathodic Protection

Research undertaken at Deakin University has led to the establishment of the National Facility for Pipeline Coatings Assessment. The only independent NATA accredited testing facility of its kind in Australia; the facility provides both a testing and research platform.

Stress Corrosion Cracking (SCC)

A team of researchers at the University of Adelaide and Deakin University has provided new insights into the mechanism and sentencing of SCC. This form of cracking in Australian pipelines has an unusual 'inclined' morphology, only reported elsewhere in Canadian pipelines. The work resulted in a clear explanation of the mechanism for the formation and growth of angled cracks, thereby providing confidence in SCC management practices used by industry.

The suite of projects on Fracture Control undertaken in Research Program 3 provide an important contribution to the understanding of fracture performance of the high strength, high toughness steels that are now common in gas transmission pipelines, for which fracture control design is largely based on the properties of steel that are unlike the steel currently used. A number of industry advisors involved in the work described this internationally acclaimed research as extremely valuable to industry.

Fracture Control is a key technical requirement of AS 2885.1 because it underlies the safety of high pressure gas pipelines. The Standard is (and will continue) to recognise significant fracture control developments from this research program. This research has developed a computer model (EPDECOM) for use in predicting the steel properties required to arrest fast tearing fracture in a natural gas pipeline. The model has been validated against the existing PRCI model (PIPEDFRAC) and against full scale burst tests. The decompression model has been validated against shock tube tests. The latest revision of AS 2885.1 recognises the application EPDECOM as the tool for predicting fracture control requirements in Australian Pipelines. This provided a mechanism for this and ongoing fracture control research to enter the Standard.

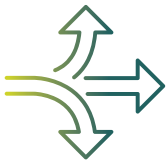
The net benefits relative to costs are likely to be considerably greater for industry than the suggested $4.50 return on every dollar invested.

This is because there is a high degree of funding leverage for industry participants, as most of the tangible benefits of research accrue to the industry participants. Moreover, the Industry end-users cash and in-kind contributions are leveraged by Commonwealth Government funding and university in-kind provisions.

The study also involved a large number of interviews with industry end-users involved in the research. Their views were universally positive; all considered that the value provided by the Energy Pipelines CRC was clearly in excess of costs. These stakeholders identified a number of other sources of research benefits not captured in the formal cost-benefit analysis, including:

International linkages

Significant value delivered through the leverage provided by partnership agreements with well-resourced overseas research organisations.



Flexibility

The Energy Pipelines CRC's ability to respond to the altered commercial environment following the demise of the Australian linepipe and coatings industries.

Access and capability

Direct access to a problem solving Australian research and testing capability.

Education and training

Professional development and career learning opportunities.

Overall the industry end-users agreed that the Energy Pipelines CRC research programs have provided the industry with value and a strong flexible research capability in Australia. As one of the industry end-users commented:

It is important to recognise that the industry doesn't always know what the questions will be, but having access to accumulated knowledge, skills and human capital helps us address emerging issues and the questions which become important to address. It is vital that we not give this away lightly.

Participants

Participant List

Australian Pipelines and Gas Association (formerly Australian Pipeline Industry Association)	2009-2019
The University of Adelaide	2009-2019
The University of Wollongong	2009-2019
Monash University	2009-2012
The Australian National University	2009-2015
Deakin University	2012-2019
RMIT University	2015-2019

During my time working under the EPCRC, I honed my skills as a pipeline engineer and that continues to propel my career as I take on larger roles within my company.

YouYou Wu, PhD Graduate

List of all APGA RSC members from 2010-2019 *SME

1 year

AGL
Beach Energy
Mark Coates*
DNV GL Oil & Gas
EPCM Consultants
Energy Safe Victoria
Monadelphous KT
Petro Coating Systems*
SpieCapag Australia
Tenix
Enscope Pty Ltd*

2 years

APLNG
ATCO Gas
Vector Gas
WAG Pipelines*
Airus Engineering*
Barbaro & Associates*
Metallurgical Eng Intl*
Papide*
Sage Consulting*
3M
Bluescope Steel
OneSteel
Anode Engineering*
CNC Project Management*
Consolidated Contracting Co Aust
CRC Evans
MPC Group (Now MPC Kinetic)
Murphy Pipe & Civil
GE Energy Oil & Gas
Petronas*
Pll Pipeline Solutions

3 years

First Gas*
Melbourne Water Corporation
Crosslinx*
Corrosion Control Engineering
LogiCamms
MJ Kimber Consultants*
Sandjohl Consulting*
Welspun

4 years

Australian Gas Networks
Multinet Gas
Tas Gas Networks*
Chris Carter Consulting*
Ross Calvert Consulting*
Scott Metallurgical Services*
Zinfra
Marubeni-Itochu Tubulars Oceanic
SA Dept of Energy & Minerals
WDS Ltd

5 years

Woodside Energy
Atteris*
Edgen Murray
JFE Steel Corp
Orrcon Steel
Tyco Water / Pentair*

6 years

Origin Energy
Brian Martin & Associates*
Momentum Engineering
Peter Tuft & Associates*
Venton & Associates*
Welding & Pipeline Integrity*
TD Williamson

7 years

GHD
Bao Australia Ltd*
Lucas Engineering & Construction (Now HDI Lucas)

8 years

Gorodok*
Viva Energy Australia (Formerly Shell Company of Australia)
Capital Projects Services*
Hatch*
OSD
UCC-Canusa*
McConnell Dowell Constructors

9 years

APA Group
John Piper & Associates*
Pipeline Research Council International
AusNet Services
DBP *
Epic Energy*
Gas Pipelines Victoria*
Jemena
Oil Search
QGC*
Santos
Geoff Cope & Associates*
Fyfe
Gemseekers International Pty Ltd
GPA Engineering*
Ninox Solutions*
Worley Parsons
ShawCor
Denso Australia*
Nacap Australia
Rosen*
CBMM

Industry and SME Engagement

The Energy Pipelines CRC was supported strongly by the Australian pipeline industry. Collaboration between industry and researchers has been substantial over the life of the CRC with industry personnel and researchers working together from research proposal to outcome assessment. The outcomes of research projects are then disseminated throughout the industry through various means allowing for high levels of uptake and implementation into practices and procedures.

A number of projects have provided secondment opportunities for researchers and industry personnel to exchange knowledge by working closely together, often in the industry. These secondments have formed an important component of the Energy Pipelines CRC's education program and have greatly assisted in preparing graduating students for employment in the pipeline industry.

The Energy Pipelines CRC has maintained strong relationships with a number of SME end users over its funding life. At least 20 SMEs have been engaged each year with the Energy Pipelines CRC as part of the 50+ members of the APGA RSC. All SMEs have the same voting rights on project development and management as the larger companies and, in practice the SMEs have regularly been more involved in the activities of the CRC.

Several SMEs have provided lead industry advisors for the research and education programs and have been actively involved in the program and project steering committees across all programs.

Many of the SMEs are consulting firms with significant industry experience over a number of years. They have encountered the various industry challenges from different angles making them well placed to assist with the development and management of research activities and with the utilisation of the outcomes.

The Energy Pipelines CRC has connections through the APGA RSC members to the various Standards Australia committees charged with reviewing and updating the AS 2885 gas and liquid petroleum pipelines suite of Standards. Energy Pipelines CRC research partners are involved in the revision of several parts of AS 2885.

The active involvement of SMEs in the research and utilisation activities of Energy Pipelines CRC has given them the best opportunity to build on their innovation and research and development capacity.

Case Study: Public Safety Research

Industry / research collaboration is at the core of the CRC Program. This has been evident within the Energy Pipelines CRC with participants working closely towards a common goal that has long term benefits for the broader industry.

Energy Pipelines CRC research program 4, Public Safety Research, has the goal of sustaining the world's best practice safety performance of Australian energy pipelines. This program analyses the human and organisational dimensions in the operation of, and interaction with, pipelines. Through CRC collaboration, a new section of the Standard AS 2885 has been developed which will provide lasting impact for both the Australian pipeline industry and the safety of the broader community.

To facilitate the relationships required between the social science community and the Australian pipeline industry, an industry-led steering committee was established to oversee and guide the research program. Furthermore, biannual regulators forums and industry-research seminars are held to ensure that the research outputs produced are relevant to, and used by, the end-user.

The uptake of public safety research by end-users is facilitated by the involvement of senior executives of major pipeline operating companies and engineering firms in the steering committee that oversees the program. This committee was initially chaired by Peter Tuft from 2010 to early 2015. Peter effectively spanned the boundary between academia and industry, connected researchers to relevant industry players and vice-versa building important relationships. Subsequent chairs have been the South Australian technical regulator, Michael Malavazos, and, currently, APA Group's Manager for National Transmission Operations, Edwin De Prinse.

The Energy Pipelines CRC regulators forum, led by the South Australian technical regulator provides a conduit between the researchers and the State/Territory technical regulators and has allowed for incorporation of research findings into regulatory practices. These forums are well attended by the State-based regulators who value the facilitated collaboration with the researchers.

Research program leader, Associate Professor Jan Hayes, was an active member of the committee working on a major update to AS 2885. This committee consisted of over 30 industry member representatives and state based regulators. Working closely with the chair of the committee, Jan sought to ensure that all relevant aspects of the social science work had been incorporated, or at least seriously considered for inclusion.

In addition to collaboration in the Australian pipeline sector, Jan also chairs an international working group involving members of the Australian Pipelines and Gas Association, the North American centred Pipeline Research Council International, and the European Pipeline Research Group. The working group, called 'Focusing on organisation safety and human factors', provides a mechanism through which research outcomes have influence internationally.

The CRC program has helped facilitate a cross-industry approach to the development of AS 2885.6. By embedding social science outcomes into a traditionally technical standard, the Australian pipeline industry can now operate with a greater degree of confidence that professional decision-making practices support long-term pipeline integrity and public safety.

My understanding is that through RP4, which is a lot about risk reduction strategies, much of that work is being taken up and heavily debated for inclusion in a new part of AS 2885; some of the research will feed straight into the document, and some of it provides a very good framework for debate about how we approach it, and to educate people and it also provides a very good understanding of where we have our limitations and constraints at the moment and how we try to cope with those in preparation of the Standard.

Steve Davies, CEO Australian Pipelines and Gas Association

International Collaborations

Canada

International Pipeline Conference

Shock Tube Testing

Norway

Joint Industry Project With DNV-GL for Carbon Capture and Storage Research

United Kingdom

Full Scale Burst Testing at the Spadeadam testing facility as part of Carbon Capture and Storage Research

France

2015 Joint Technical Meeting attended in Paris

United States

2017 Joint Technical Meeting on Pipeline Research attended in Colorado Springs, Colorado

Engagement with PRCI

Brazil

Student Study Tour to international Steel Manufacturer


Germany
Engagement with European Pipeline Research Group
China
BAJC interactions, study tours, other research activities
Netherlands
Research Program Four leader interactions at the University of Twente
Belgium
Presentations at Ostend pipeline technical conference
Australia
Engagement with Australian Pipeline Industry and Major Universities. Participation and presentation in a number of conferences, seminar and other events

Carbon Capture and Storage Research

Over the period 2011 – 2014 the Energy Pipelines CRC completed a significant program of work for the former Department of Resources, Energy and Tourism on pipelines for the transport of carbon dioxide (CO_2). This work focussed on the provision of information that would allow the extension and use of the Standard AS2885.1 to cover CO_2 pipelines. The Standard has now been updated as envisioned.

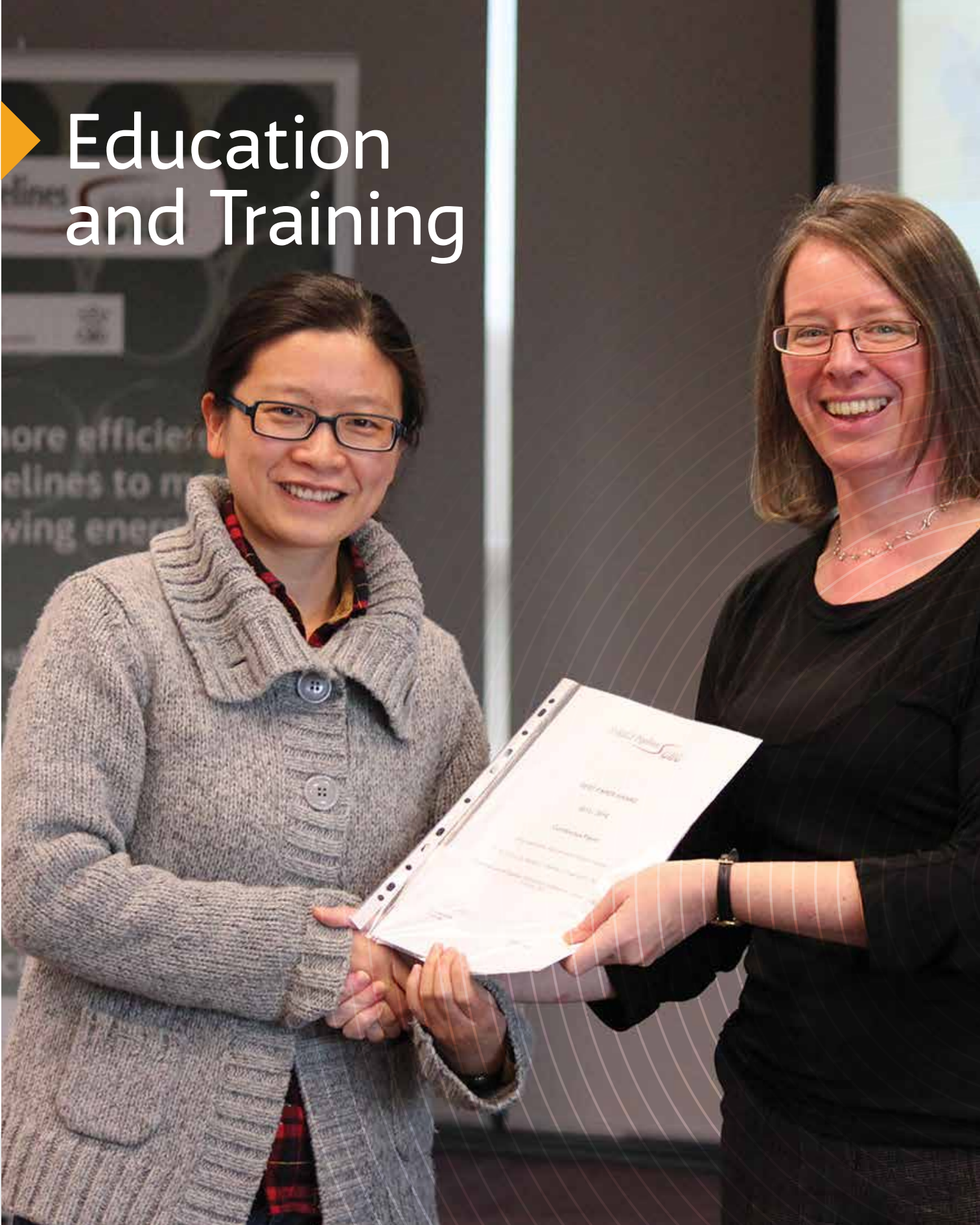
Input to the development of the International Standards Organisation (ISO) Standard ISO27913 'Carbon Dioxide capture, transportation and geological storage – pipeline transportation systems' has also been provided and the standard is now complete and published.

From 2016 to 2019, the Energy Pipelines CRC was part funded from the Australian Government's Department of Industry, Innovation and Science (DIIS) under the Carbon Capture and Storage Research Development and Demonstration (CCS RD&D) Fund to work on fracture control modelling and dispersion modelling following a CO_2 pipeline rupture. The company partnered with DNV GL (Norway) to deliver this work. Two full scale burst tests were undertaken in late September 2017 and early March 2018 as part of the project. The project was successfully completed in April 2019 and resulted in a new software model for fracture control and dispersion and recommended updates to Australian and international Standards and recommended practices.

My involvement with the EPCRC ensured that I was able to hit the ground running into a role in North America and smoothly transfer between the academic world to the operator world. This was thanks to the close relationship with industry that the EPCRC afforded, helping one "soak in" the language, philosophy, priorities and culture of the pipeline industry.

Erwin Gamboa, Former Senior Researcher

Education and Training



Educational Outputs

The Energy Pipelines CRC program provided a beneficial and significant exchange of knowledge to and from the researchers and industry personnel.

> Involvement in the EPCRC has been immensely useful to me as a design engineer, and also to GPA Engineering in general
>
> **Nick Kastelein, GPA Engineering.**

Impact of Education Program

Postgraduates

Over the life of the CRC, 23 HDR students have graduated with their PhD and 2 HDR students have graduated with their Masters. Of the 25 students who have graduated, 24 are employed in the pipeline industry or in pipeline-related research. There have been 25 industry members involved in co-supervision of the Energy Pipelines CRC HDR students. A large proportion of the industry members have been involved with more than one of the HDR research projects.

Educational Outputs

One of the main mechanisms for transferring the knowledge gained through research activities to industry is through the development and delivery of coursework units. The majority of coursework units are delivered at research seminars (held twice per year) and at the annual researcher conferences. There have also been structured professional training courses arising from the CRC's work such as intensive one-day workshops.

Close to 200 coursework units have been recorded and uploaded to the members' area of the Energy Pipelines CRC website for ongoing access.

Secondments

The direct involvement of leading industry specialists in the research activities has resulted in a beneficial and significant exchange of knowledge to and from the researchers and the industry.

Education Program Key Statistics

35

Number of students who started a PhD or Masters

23

Number of graduated HDR Students (PhD)

2

Number of graduated HDR Students (Masters)

24

Number Employed in pipeline industry or in Pipeline related research

19

Full Day Research Seminars

8

Researcher Conferences

186

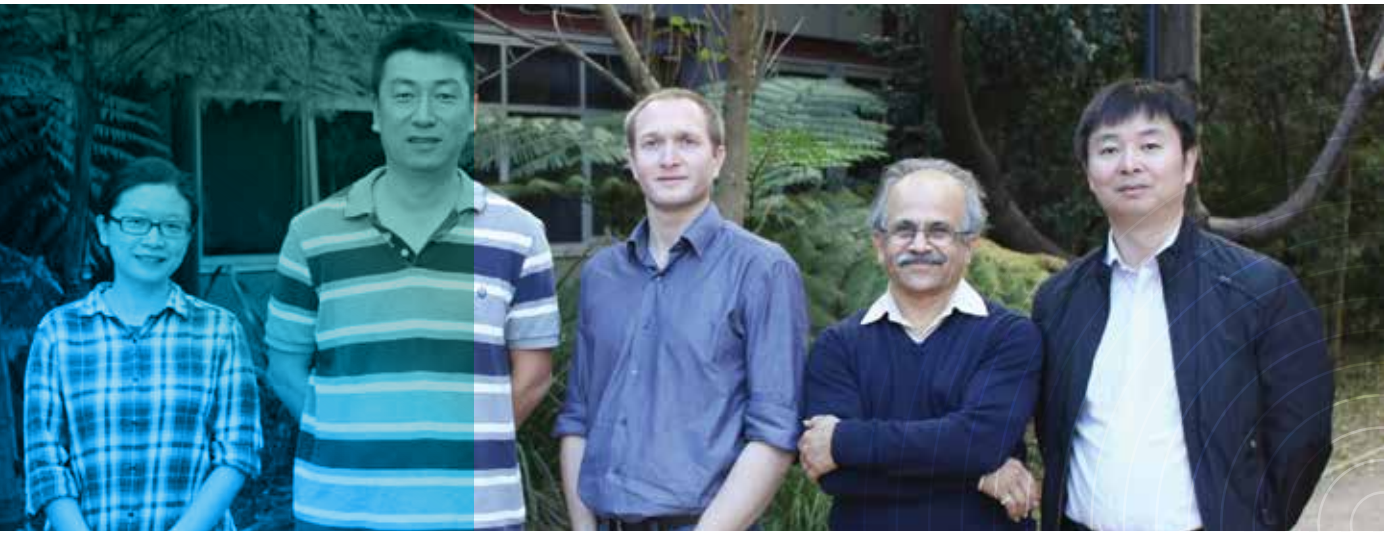
Coursework units presented

10+

Students who have been on field placements

80+

Number of industry people involved in research projects



Case Study: Fracture Control in Gas Pipelines

Fracture of a pipeline can have catastrophic effects in terms of danger to life and damage to property. Minimising the risk of fracture through detailed design is a critical activity.

The Energy Pipelines CRC completed breakthrough work on the understanding and control of fracture. Knowing that it is vital to disseminate knowledge and have it adopted by the pipeline industry, a one-day intensive workshop on fracture control was held in July 2012 to:

- Enhance the understanding across the pipeline industry of the accuracy of the existing fracture control plan development tools and their practical application;
- Provide an update on the latest findings from the Energy Pipelines CRC research and their practical application;
- Develop an understanding of the role of pipe internal roughness and pipe diameter on the fracture control behaviour of energy pipelines; and
- Introduce participants to the upcoming launch of new fracture control software EPDECOM

The 30 people attending this initial workshop were from a broad range of backgrounds, including people specifying pipe for purchase or preparing fracture control plans, pipeline engineers in operating and consulting companies, material suppliers and researchers.

Subsequently, there have been 7 additional coursework units on fracture control delivered at the research seminars, covering a broad range of topics ranging from the launch of the fracture control software EPDECOM through to design of pipelines for natural gas and carbon dioxide.

The fracture control software EPDECOM, developed by the research team at UOW, is now recommended in AS 2885 for fracture control design and roll-out seminars were organised following reviews of the Standard to present further findings.

Seminars

Biannual Research Seminars were held from 2010 to 2018 providing updates on all research programs as well as specific research projects that have reached a specific milestone. Keynote speakers often present at these events providing fresh perspective on industry issues.

Conference

The annual Researcher Conference provided an opportunity to bring together the Energy Pipelines CRC Research Team for networking and professional development as well an opportunity for industry members to provide intensive masterclasses on various sectors of the Australian pipeline industry.

CEO's Final Note

Robert Newton

The Energy Pipelines CRC was formed by a group of highly committed industry specialists and academics who recognised the compelling need for industry led quality research to resolve a number of issues and to provide input into the Australian pipeline Standards.

It would be difficult to cover all of our activities and achievements in one document but we trust that the information provided gives some insight.

Our reason for being was based around extending the life of the existing natural gas transmission network and to build better, cheaper and safer networks to meet increasing consumer demand through collaborative research. We did not seek publicity for our outcomes, other than within the pipeline community. Additionally, our research was aligned to reducing costs rather than dramatically increasing revenue. There have been a few hurdles along the way and there have been a few areas where we have not achieved all of our goals. Overall, I believe our successes have been far greater than our original expectations.

I wish to thank those who were involved in the formation of Energy Pipelines CRC – particularly, Leigh Fletcher, Phil Venton, Peter Tuft, Max Kimber, Richard Robinson and Valerie Linton. Thank you also to Ankie Larsson and Peter Heffernan for their work in establishing the company. Valerie's leadership over the first 6 years of the Energy Pipelines CRC has been a key reason for our success.

Thank you to the Energy Pipelines CRC staff – former CEO David, Klaas, Matt, Fari and Lyndal, Board and Committee members past and present, and the industry advisors and researchers who have given so much of their time to make the Energy Pipelines CRC so successful.

It is important that the conclusion of the Energy Pipelines CRC should not reduce the commitment to industry led pipeline research. A continuing commitment to research is vital to any economy and particularly within an industry where there is rapid change.