Australian Government

Australian Renewable Energy Agency

Renewable Energy Research and Development in Australia's Universities

A Discussion Paper

Produced and written by: Australian Research Council

Location: Level 2, 11 Lancaster Place
Majura Park ACT 2609

Postal Adress: GPO Box 2702
Canberra ACT 2601

Telephone: +61 2 6287 6600
Facisimile: +61 2 6287 6601
Email: info@arc.gov.au (general enquiries)
era@arc.gov.au (Excellence in Research for Australia enquiries)

ISBN 978-0-9807997-9-8

© Commonwealth of Australia 2013

This work is copyright. Apart from any use as permitted under the Copyright Act 1968, no part may be reproduced by any process without prior written permission from the Commonwealth. Requests and inquiries concerning reproduction and rights for this document should be addressed to the Executive General Manager, Australian Research Council, GPO Box 2702, Canberra, ACT 2601 or communications@arc.gov.au.

Contents

Executive Summary

- Australian Renewable Energy Technologies (RETechs) research includes a diverse range of technologies, but there is a clear concentration in solar cells research
- RETechs research in Australian universities is performed mostly within Engineering disciplines
- The research disciplines that underpin RETechs research are high-performing within Excellence in Research for Australia (ERA), which has identified research units at or above world class across all underpinning disciplines
- RETechs research papers perform exceptionally well on average on key citation indicators – above the average for their underpinning disciplines, and between 1.6-3.9 times the world average
- Publication of RETechs research grew in Australia at a rate of 13% across the reference period, 2005-2010

The Discussion Paper provides a 'conceptual map' of the R&D effort into RETechs, to assist ARENA in developing their theme-based funding rounds: for example, which are the particular RETechs that are being researched, and to what degree of concentration this is occurring.

The Discussion Paper finds that the R&D effort can be classified into a number of discrete research areas in order of their share of RETechs publications:

Hydrodynamics, inverters and hybrids
- Smoothed particle hydrodynamics (ocean power)
- Energy inversion
- Blades and turbines

Solar Cell Technologies B
- Dye sensitized solar cells
- Multijunction photovoltaic cells

Hydrogen and Biofuel
- Solar-hydrogen systems
- Bio-mass
- Bio-fuels
- Blades and turbines

Wind and converters
- Hybrid wind power (especially diesel-wind hybrid)
- Energy conversion
- Blades and turbines

Building
- Sustainable building
- Blades and turbines

Solar cell technologies A
- Quantum dot/crystalline silicon solar cells
- Modelling for solar cells

Batteries and Geothermal
- Lithium ion battery storage
- Blades and turbines

Amongst these, there is a concentration of research into solar cells split over two clusters. A large proportion of the RETechs research identified in this Discussion Paper was into solar cells, and within this, there were several technologies being researched: crystalline silicon solar cells, dye sensitized solar cells and multijunction photovoltaic cells were all prevalent within RETechs research. While a number of other technologies were evident in the data, these were all relatively diffuse in comparison. One reason for this may be that they are relatively emerging technologies, and so are less identifiable as a homogenous grouping.

Though this clustering technique assists in describing the diversity of Australian RETech research in Australian universities and the CSIRO, it does not readily provide indicators of the quality of research for any given technology. To provide indicators of the quality of RETech research, investigation into the disciplines found to underpin RETech research in Australia has been used.

RETechs research in Australian universities is concentrated in Engineering disciplines, primarily in Materials Engineering, and in Electrical and Electronic Engineering. There is also significant output in Condensed Matter Physics. These key discipline Groups are judged to be high-performing within the ERA evaluation exercise, which has identified research at or above world standard within these disciplines. While RETechs research comprises a small focus of these disciplines, they provide a stable base of world standard research quality to sustain RETechs research.

Within these underpinning disciplines, the RETechs research performed very well on key citation indicators used in this study – not only were RETechs research papers cited on average more frequently than the underpinning research disciplines, they were cited between 1.6 and 3.9 times the world average. Such data identify RETechs research in Australia as a pocket of national strength. RETechs research within CSIRO similarly displays high performance on key citation indicators, with research into Energy and Fuels 59% (or around 1.6 times) more cited than the global average.

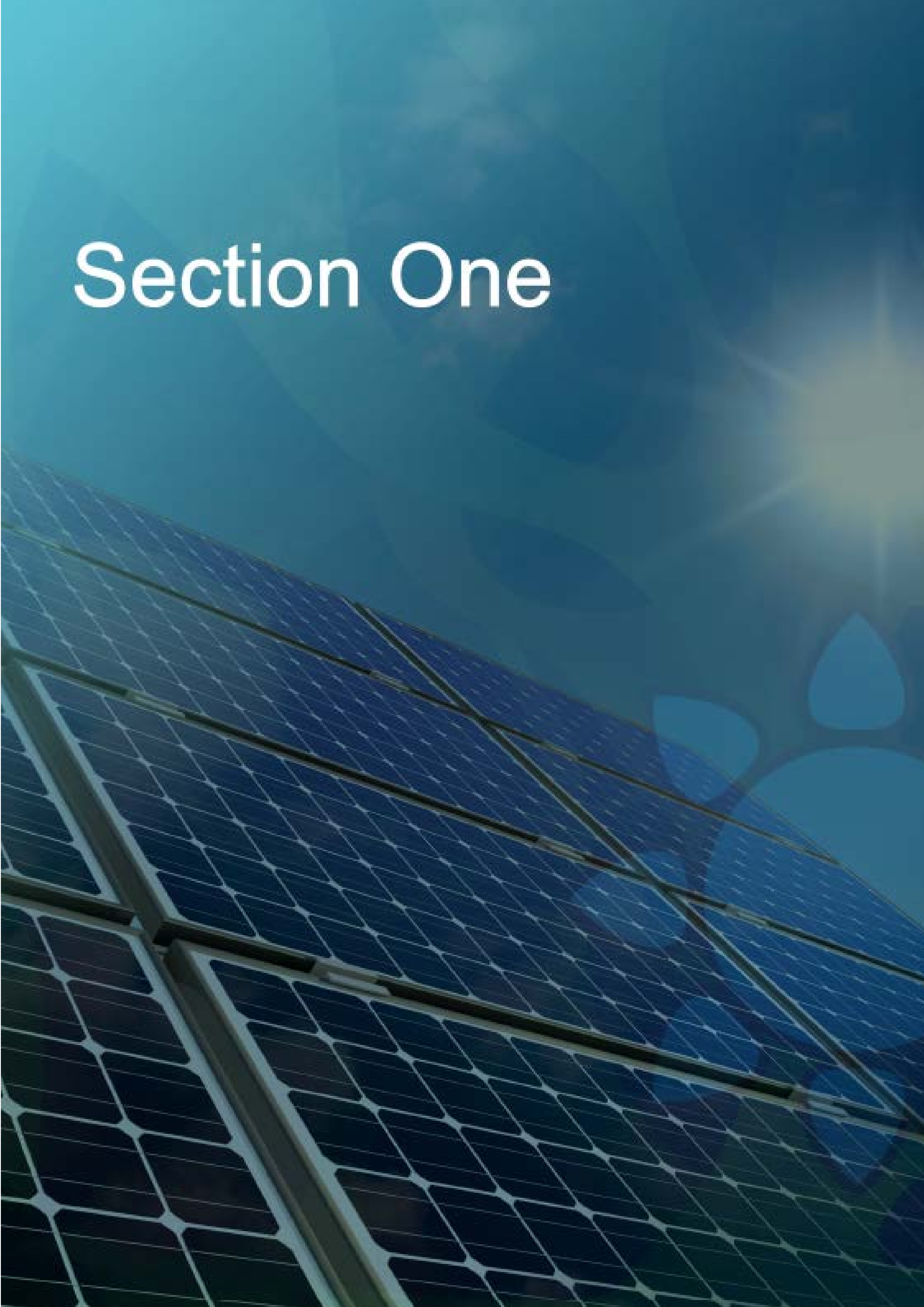
The contribution of both universities and CSIRO increased across the study period, with CSIRO RETechs research growing an annual average of 23% between 2005 and 2010.

The combination of high performing underlying disciplines with a pocket of very high-performing RETechs research potentially has identified areas of research strength and therefore supports the case for further investment in RETechs research.

Figures

Tables

Section One



Introduction

Profile of ARENA

The Australian Renewable Energy Agency was created by the Australian Renewable Energy Agency Act 2011 and the Australian Renewable Energy Agency (Consequential Amendments and Transitional Provisions) Act 2011 and began operations on 1 July 2012. It is an independent statutory authority.[1]

Its primary objectives are improving the competitiveness of Renewable Energy Technologies (RETechs) and increasing the supply of renewable energy in Australia. ARENA has a significant budget to fund renewable energy projects, to provide support for research and development, and to support activities to capture and share knowledge.[2]

The ARENA organisational structure includes the ARENA Board, the CEO, the ARENA Advisory Panel, and Departmental staff that provide ARENA with operational and administrative support. The ARENA Board is made up of the Secretary of the Department of Industry and six further members appointed by the Minister for Industry who have skills in renewable energy technology, commercialisation, business investment or corporate governance. The Board is an independent decision-making body for allocating ARENA funds. The Minister appoints the CEO on recommendation of the Board. The ARENA Advisory Panel's role includes assessing program funding applications and providing expert advice that supports the development and project selection for ARENA funding.[3]

ARENA Funding

The ARENA General Funding Strategy and its Investment Plan provide a framework for its funding support for RETechs.
In making funding decisions, ARENA aims to produce a portfolio of investments that meets its objectives of improving the affordability and increasing the supply of renewable energy. To achieve this, ARENA's investment strategy is based on the following three types of initiatives:

Tier 1 – Strategic Initiatives:
Strategic initiatives are larger in scope and scale and typically fund market-oriented, near commercial, projects. While ARENA expects to implement only a small number of strategic initiatives over time, this is where the bulk of ARENA's funding is likely to be allocated, given the costs associated with large scale demonstration and deployment.

Tier 2 – Supporting Initiatives:
Supporting initiatives are of more limited scope and address specific roadblocks to the success of a strategic initiative; they may also create the pre-conditions necessary for the emergence of the next generation of strategic initiative solutions. As their name implies, the purpose, design and timeframe of supporting initiatives will be strongly defined by the strategic initiative they are supporting.

---

[1] *Established under the Commonwealth Authorities and Companies Act 1997.*

[2] *Source: ARENA website 2013: http://www.arena.gov.au/about-arena/*

[3] *Ibid.*

Tier 3 – Complementary Initiatives: Complementary initiatives provide ARENA with the flexibility to invest in a diverse range of opportunities maximising the prospects of ultimately fulfilling all of its functions. These initiatives may have a wider scope and often address themes common to multiple initiatives, helping balance the ARENA portfolio. ARENA anticipates that this tier of the investment strategy will support a diverse mix of activities and provide scope for trialling more innovative funding model.[4]

Scope of this Discussion Paper

This Discussion Paper provides ARENA with detailed information on R&D into RETechs in Australian universities and within the Commonwealth Scientific and Industrial Research Organisation. It identifies existing areas of research strength that might meet ARENA's funding objectives as well as areas that may be relevant to Australian specific-conditions. The Discussion Paper undertakes the following key tasks:

- Task 1 – Detail and explain the research areas of universities and CSIRO within the scope of the study.
- Task 2 – Outline a methodology to evaluate the quality of these research areas.[5]

Definition of Renewable Energy Technology

For the purpose of this Discussion Paper ARENA defines renewable energy as "energy which can be obtained from natural resources that can be constantly replenished". RETechs are "technologies that use – or enable the use of – one or more renewable energy sources." Types of renewable energy and related technologies are outlined in Box 1.

[4] *Source: ARENA Investment Plan 2013/14-2015/16: http://www.arena.gov.au/_documents/2013-14-IP.pdf*

[5] *The tasks are detailed further in Appendix A: Request for Services.*

Box 1– Types of Renewable Energy and Technology

Bioenergy
Bioenergy is a form of renewable energy derived from biomass to generate electricity and heat or to produce liquid fuels for transport. Biomass is any organic matter of recently living plant or animal origin. It is available in many forms such as agricultural products, forestry products, and municipal and other waste.

Geothermal energy
Geothermal energy is the energy stored as heat in the earth. In Australia, this energy is abundant.

There is a steady flow of heat from the centre of the Earth (where temperatures are above 5000°C) through the surface of the Earth (-30 to +40°C) into space (-273°C)—heat flows from hot to cold. The heat is generated by the natural decay over millions of years of radiogenic elements including uranium, thorium and potassium.

Energy is brought to the surface by extracting hot water that is circulating amongst the sub surface rocks, or by pumping cold water into the hot rocks and returning the heated water to the surface, to drive steam turbines to produce electricity.

Hybrid and related technologies
A hybrid technology is one that integrates a renewable energy generation technology with other energy generation systems. An example of a hybrid technology would be a power plant which combines solar-based thermal energy with thermal energy from gas or other renewable energy sources, to provide a combined energy flow that drives the power generation from the plant.

Technologies that are related to renewable energy technologies include: energy storage technologies, grid management and connection technologies, information and communication technologies, mapping and resource identification technologies, and forecasting and modeling technologies.

Hydropower
Hydropower is a renewable source of energy which uses the force or energy of moving water to generate power.

This power, or ‘hydroelectricity’, is generated when falling water is channelled through water turbines. The pressure of the flowing water on turbine blades rotates a shaft and drives an electrical generator, converting the motion into electrical energy.

Ocean energy
‘Ocean energy’ is a term used to describe all forms of renewable energy derived from the sea.

There are two broad types of ocean energy: mechanical energy from the tides and waves, and thermal energy from the sun’s heat.

Ocean energy is classified as:

- wave energy—generated by converting the energy of ocean waves (swells) into other forms of energy (currently only electricity). There are many different technologies that are being developed and trialled to convert the energy in waves into electricity.
- tidal energy—generated from tidal movements. Tides contain both potential energy, related to the vertical fluctuations in sea level, and kinetic energy, related to the horizontal motion of the water. It can be harnessed using technologies using energy from the rise and fall of the tides or by technologies using energy from tidal or " marine currents.
- ocean thermal energy—generated by converting the temperature difference between surface water and water at depth into useful energy. Ocean thermal energy conversion (OTEC) plants may have a range of applications for Australia, including electricity generation. They may be land-based, floating or grazing.

Solar energy

Solar energy is energy which is created from sunlight, or heat from the sun.

Solar power is captured when energy from the sun is converted into electricity or used to heat air, water, or other fluids.

There are currently two main types of solar energy technologies:

- solar thermal—these systems convert sunlight into thermal energy (heat). Most solar thermal systems use solar energy for space heating or to heat water (such as in a solar hot water system). However this heat energy can be used to drive a refrigeration cycle to provide for solar based cooling. The heat can also be used to make steam, which can then be used to generate electricity using steam turbines. It is considered more efficient to build solar thermal electricity generators at large scale, typically in the tens to hundreds of megawatts.
- solar photovoltaic (PV)—the conversion of sunlight directly into electricity using photovoltaic cells. PV systems can be installed on rooftops, integrated into building designs and vehicles, or scaled up to megawatt scale power plants.

Wind energy

Wind energy is generated by converting wind currents into other forms of energy using wind turbines.

Winds are generated by complex mechanisms involving the rotation of the Earth, the heat capacity of the Sun, the cooling effect of the oceans and polar ice caps, temperature gradients between land and sea, and the physical effects of mountains and other obstacles.

Wind turbines convert the force of the wind into a torque (rotational force), which is then used to propel an electric generator to create electricity. Wind energy power stations (known as wind farms) commonly aggregate the output of multiple wind turbines through a central connection point to the electricity grid. Across the world there are both on-shore (on land) and off-shore (out to sea) wind energy projects.

Source: ARENA website 2013: www.arena.gov.au/about-renewable-energy/

About Data Sources

To identify research in RETechs this Discussion Paper makes use of a number of data sources, including data collected and evaluated under Excellence in Research for Australia 2012 and Elsevier Scopus (herein Scopus) custom world dataset.

Excellence in Research for Australia (ERA): ERA Aims and Objectives

ERA aims to identify and promote research excellence in Australia's universities. It evaluates the full spectrum of research activity, including discovery and applied research, across the Sciences, Technology, Social Sciences, Humanities and the Arts. The objectives of ERA are to:

- establish an evaluation framework that gives government, industry, business and the wider community assurance of the excellence of research conducted in Australian higher education institutions;
- provide a national stocktake of discipline level areas of research strength and areas where there is opportunity for development in Australian higher education institutions;
- identify excellence across the full spectrum of research performance;
- identify emerging research areas and opportunities for further development; and
- allow for comparisons of Australia's research nationally and internationally for all discipline areas.[6]

ERA Data

The ERA data consists of a comprehensive collection of research articles from all 41 of Australia's universities (a list of the universities evaluated as part of ERA is provided at Appendix B: Institutions evaluated in ERA 2012). ERA 2012 collected data on 413 477 research publications and 60 668 researchers.

ERA collects data based on the Australian and New Zealand Standard Research Classification Fields of Research (FoR) codes. ERA assesses research quality by unit of evaluation (UoE). A UoE is the discipline area within a university that has a sufficient research volume (i.e. 50 or more apportioned research outputs/articles) to meet the threshold for research activity. ERA 2012 assessed 2 323 UoEs.

ERA 2012 captured research outputs published from 1 January 2005 to 31 December 2010. Of the 413 477 research outputs submitted, 69% were journal articles, 18% conference papers, 10% book chapters, 2% non-traditional research outputs (NTROs) and 1% books. This Discussion Paper makes use of journal article data as this is the primary output type for the disciplines under consideration. Custom citation data (including world benchmarks and individual article citation counts) supplied by Scopus for ERA 2012 evaluations is used where references are made to citations and Specialisation Indexes (SI) throughout this Discussion Paper.

The ERA data collection will be updated for the next round of ERA which is scheduled for 2015.

[6] *Source: Excellence in Research for Australia (ERA) 2012 National Report: www.arc.gov.au/era/era_2012/outcomes_2012.htm*

ERA Evaluations

Eight ERA Evaluation Committees (EECs) of internationally recognised experts determine quality ratings for each UoE based on the ERA data. The ERA 2012 decisions took into account four broad categories of indicators:

1. Indicators of research quality: Research quality was considered on the basis of a publishing profile, citation analysis, ERA peer review, and peer reviewed Australian and international research income.
2. Indicators of research volume and activity: Research volume and activity was considered on the basis of total research outputs, research income and other research items within the context of the profile of eligible researchers.
3. Indicators of research application: Research application was considered on the basis of research commercialisation income, patents, Plant Breeder's Rights, registered designs, and NHMRC endorsed guidelines. Some other measures, such as publishing behaviour and some other categories of research income, can also provide information about research application.
4. Indicators of Esteem: Research recognition was considered on the basis of a range of esteem measures.[7]

The ERA quality ratings applied are included in Table 1.

The results for universities and UoEs are published in the ERA National Report at the conclusion of the evaluation process.[8]

Table 1 ERA Rating Scale

Rating	Descriptor
5	The Unit of Evaluation profile is characterised by evidence of outstanding performance **well above world standard** presented by the suite of indicators used for evaluation.
4	The Unit of Evaluation profile is characterised by evidence of performance **above world standard** presented by the suite of indicators used for evaluation.
3	The Unit of Evaluation profile is characterised by evidence of average **performance at world standard** presented by the suite of indicators used for evaluation.
2	The Unit of Evaluation profile is characterised by evidence of performance **below world standard** presented by the suite of indicators used for evaluation.
1	The Unit of Evaluation profile is characterised by evidence of performance **well below world standard** presented by the suite of indicators used for evaluation.
NA	Not assessed due to low volume. The number of research outputs does not meet the volume threshold standard for evaluation in ERA.

[7] *Source: Ibid.*

[8] *See further: Commonwealth of Australia, 2012, Excellence in Research for Australia Field of Research List, www.arc.gov.au/era/Outcomes_2012/FoRIndex for results by discipline.*

Commonwealth Scientific and Industrial Research Organisation

This Discussion Paper incorporates research articles with identifiable RETechs research content from the Commonwealth Scientific and Industrial Research Organisation. It also includes analysis from the CSIRO Research Excellence team, which makes use of a number of commercial citation analysis products.

CSIRO is Australia's national research agency and its activities encompass a broad range of scientific enquiry and engagement in diverse fields such as information and communications technologies, agriculture, oceans and climate, and minerals exploration. Research activity within the agency is significantly located within a National Research Flagship program (see Box 2 below for more detail) which is designed to foster collaboration between CSIRO, universities and other publicly-funded research agencies to address major national and global challenges.

The work of the Energy Transformed Flagship is of particular interest for the purposes of the ARENA study. This Flagship has a focus on energy production and use with an overall aim to:

- improve the affordability, reliability and grid integration of renewable energy technologies – including solar, wind and biofuels
- provide the transport sector with sustainable fuels and energy storage solutions
- improve the way Australia uses energy at home and at work by using new technologies and improving the electricity grid
- provide government and industry with the tools, data and modelling capability to inform policy assessment and investment decision making.[9]

[9]*Source: Energy Transformed Flagship Overview: www.csiro.au/org/Energy-Transformed-Flagship-Overview*

Box 2 CSIRO National Research Flagships

Box 2 - CSIRO National Research Flagships

Since the launch of its first three National Research Flagships in 2003, CSIRO has committed an increasing proportion of its resources to addressing major national challenges and opportunities through the National Research Flagships Program. The Flagships address complex challenges by forming large-scale multidisciplinary research partnerships with Australian universities and publicly- funded research institutions, the private sector and selected international organisations.

In 2012–13, CSIRO devoted 49 per cent of its resources to its 11 National Research Flagships:

- Biosecurity
- Climate Adaptation
- Digital Productivity and Services
- Energy Transformed
- Food Futures
- Future Manufacturing
- Minerals Down Under
- Preventative Health
- Sustainable Agriculture
- Water for a Healthy Country
- Wealth from Oceans.

Through the National Research Flagships Program [CSIRO intends] to concentrate on strategic research, knowledge and technology transfer with the potential to deliver major long-term social, economic and environmental benefits to Australia. The Flagships target clearly defined goals, framed from a careful analysis of the needs of people and enterprises and have a strong focus on the adoption of research outputs to deliver positive impact for the nation.

Source: CSIRO: www.csiro.au/Organisation-Structure/Flagships/AboutNationalResearchFlagships.aspx

The Scopus Dataset

The Scopus Custom World Dataset held by the ARC comprises over 12 000 000 bibliographic records of international research publications. CSIRO and university research articles in this Discussion Paper have been identified within the Scopus dataset and their bibliographic records are the basis for further analysis.

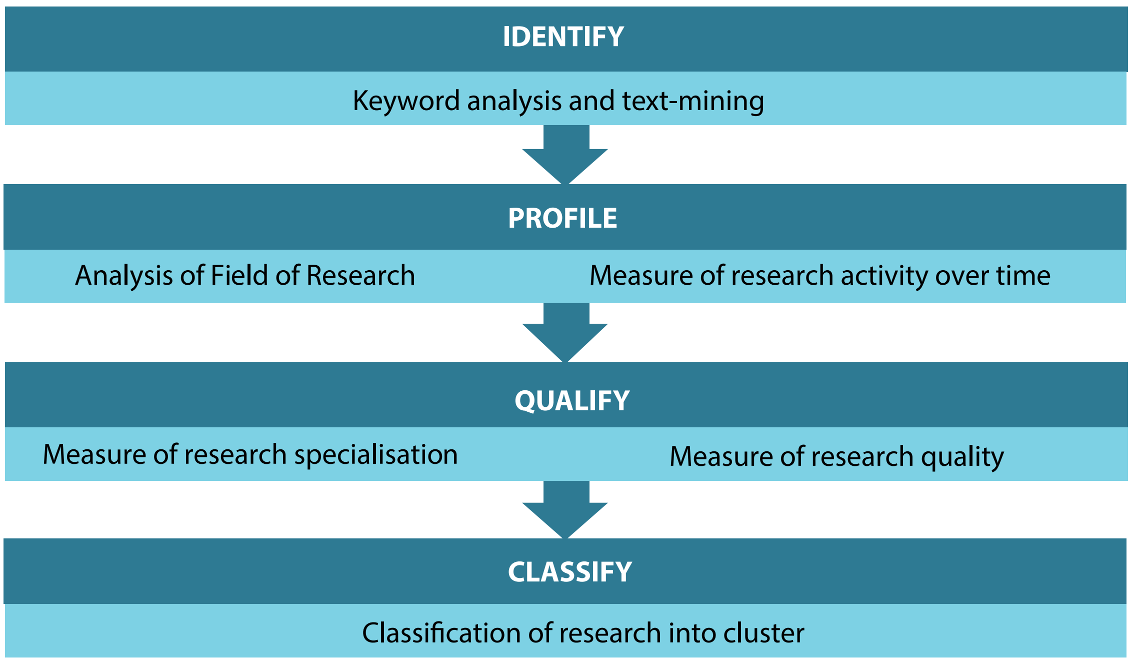
ARENA Study Methodology

Approach

The approach of this Discussion Paper is outlined below.

A dataset of universities’ and CSIRO’s research was developed using text mining techniques and keywords to identify articles relevant to RETechs. These articles are the basis of the detailed analysis in the Discussion Paper.

Figure 1 Summary of Discussion Paper approach



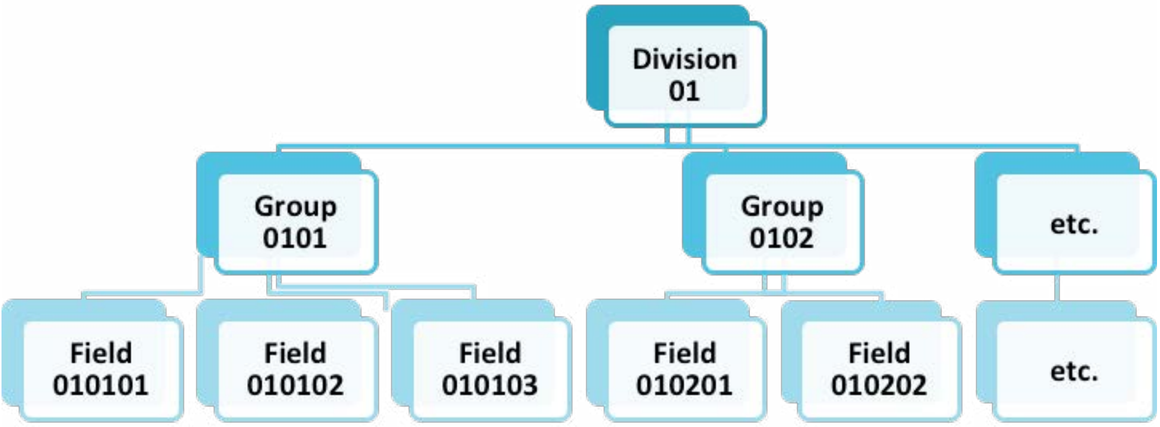
Australia and New Zealand Standard Research Classification (ANZSRC)

The ANZSRC is the agreed classification standard for the measurement and analysis of research and experimental development in Australia. The ANZSRC comprises three types of classification: Fields of Research; Socio-Economic Objectives (SEO); and Types of Activities (ToA). ERA data is collected by FoR code and so where possible the outcomes presented in this Discussion Paper are based on this classification.

The FoR code structure provides a hierarchical classification consisting at the highest level of twenty two two-digit Division codes, with one hundred and fifty seven four-digit Group codes, and an extensive range of six-digit Field codes as in the following example:

The two-digit Division is the highest level of the FoR hierarchy. A two-digit Division code relates to a broad discipline field, such as '09 Engineering'. Within that two-digit code is a range of four-digit Group codes, such as '0902 Automotive Engineering', '0910 Manufacturing Engineering', and others. The four-digit Group consists of related six-digit Field codes. The Field code '090509 Water Resource Engineering' is within '0905 Civil Engineering'. ERA data is collected at the four-digit level which allows the data submitted to be re-compiled at the two-digit level. ERA does not collect data at the Field or six-digit level.

Figure 2 FoR code structure



Limitations on ANZSRC FoRs

The FoR codes provide for research to be classified according to the underlying methodology that is used. While the ERA approach to coding allows for a fine-grained assignment based on the FoR contributions within each research publication[10], the FoR codes do not apply to broad activities such as RETechs which do not present an agreed methodology. The ANZSRC SEO classification does provide some relevant coding. In the '85 Energy' code for example there is a classification of '8505 Renewable Energy' which includes '850501 Biofuel (Biomass) Energy', '850502 Geothermal Energy' and '850503 Hydro-Electric Energy'.

However, there is no research data collection that uses the SEO codes to collate information that could be used for the current Discussion Paper.

Like any coding framework, the structure provided by the ANZSRC is designed for purpose and so has limitations beyond that purpose. The distribution of codes within the framework can be difficult to navigate. So, for example, related four-digit codes may be located across multiple two-digit codes as in the example of some areas of Materials Science which can be found in '02 Physical Sciences', '03 Chemical Sciences', '09 Engineering Sciences', and '10 Technology' two-digit codes.[11]

An area of research such as RETechs is not readily identifiable in the FoR codes at the two- or four-digit levels. Indeed, even at the six-digit level there are only a limited number of codes which are focused on renewable energy and fuels as follows:

Table 2 Six-digit FoR codes related by title to RETechs

4 digit discipline group	6 digit discipline field
0902 Automotive Engineering	**090201** Automotive Combustion and Fuel Engineering (incl. Alternative/Renewable Fuels)
0904 Chemical Engineering	**090405** Non-automotive Combustion and Fuel Engineering (incl. Alternative/Renewable Fuels)
0906 Electrical and Electronic Engineering	**090605** Photodetectors, Optical Sensors and Solar Cells **090608** Renewable Power and Energy Systems Engineering (excl. solar cells)
0913 Mechanical Engineering	**091305** Energy generation, Conversion and Storage Engineering

[10]ERA has been designed to provide flexibility for discipline-specific research behaviours at both the four-digit and two-digit FoR code levels. ERA allows for the multiple coding of outputs to ensure that work is appropriately located. In ERA, research outputs often fall outside of a single discipline, and so outputs can be apportioned across multiple FoR codes to recognise the multi-disciplinary nature of some research e.g. a single research paper can be apportioned 0.5 to FoR 0104 (Statistics) and 0.5 to FoR 1608 (Sociology). There is no restriction on coding for the majority of output types beyond a maximum of three codes being allowed. A journal article is bound by the codes agreed through consultation with the Higher Education sector which attach to the journal in which the work is published. However, a re-assignment process allows institutions to code a journal article with significant content (66% or greater) not represented by the journal's FoR(s) to the FoR code that best describes the content.

[11]The ANZSRC FoR codes provide alternative groupings for some research areas such as Aboriginal and Torres Strait Islander Studies, Maori Studies and Pacific People Studies. These consist of groupings of related six-digit Fields. No such grouping exists for 'Renewable Energy' research.

An approach which relied on these codes alone would potentially give a very narrow view of research on RETechs. The approach in this study is to interrogate the ERA dataset in more detail using text mining techniques to identify the RETechs research content of the research articles which were submitted for the ERA 2012 exercise.

Text mining

Text mining is an analytic method which processes textual data, extracting information such as keyword and phrase frequencies, pattern recognition, and document and term clustering. By applying text mining techniques, specific research areas and concepts related to RETechs can readily be identified within the data.

The real strength of text mining is the ability to move beyond the classifications of disciplines and identify the key technologies or concepts being used within the research. To do this, the ARC has worked with ARENA to develop a list of keywords which cover the main aspects of RETechs research (Appendix C: ARENA Keywords).

The keywords supplied by ARENA have been matched against research articles in the Scopus dataset to identify all relevant research articles – the articles have been attributed back to universities through linking with the ERA 2012 data and to CSIRO in collaboration with CSIRO's Science Excellence team. Each output is checked for whether it matches against one or more keywords and receives a score between 0-1000 to determine the significance of the match. Appendix D: Ranking Algorithm for Keyword match provides the detail of the matching algorithm.

Lists of the articles' titles, as well as their rank against the keywords, were provided to ARENA to determine from a discipline-perspective which ranking was relevant to which keyword (i.e. at which rank the articles stopped being relevant to a given keyword). This ensures that over-reporting of results does not occur; at the same time, it is likely that this under-reports the results as it will inevitably exclude some lower ranked, but relevant articles. Further, it is likely that this approach will under-report results to some extent as it relies upon the appropriateness of the keywords to match the articles (i.e. the better the keywords match the research articles, the more relevant the matched articles will be).

For the university-attributed publications, this method allows for the research articles to be allocated back to the two-digit Divisions and/or four-digit Groups, as each output sits within these structures in the ERA dataset. That in turn allows for research in RETechs to be described in terms of the disciplinary contributions and to identify where there may be any significant interdisciplinary contributions.

Relative Citation Impact

A primary performance indicator used in this Discussion Paper is the Relative Citation Impact (RCI). The RCI represents the average weighted[12] citation performance for a group of articles normalised against the year and discipline in which each output is published. An RCI of 1 means that a group of articles is equal to the world average citation performance, while an RCI greater than 1 indicates above world average citation numbers.

The citation methodology used in this Discussion Paper (Appendix E: Citation Benchmark Methodology) recognises that each discipline has distinctive citing behaviours and publication timelines. For this reason it uses four-digit Group code specific benchmarks. To normalise for different citation rates in different disciplines, the citation performance of an article published in a particular four-digit FoR is only ever compared against the performance of other articles published in the same four-digit FoR. To normalise for different citation windows across the six-year period under analysis, a paper is only ever compared against articles published in the same year. These two measures address the impact of any field specific citing behaviours, and normalises for the time taken to accumulate citations.

Calculating the citation performance of each article in this way allows for the performance of individual articles to be recompiled into larger, aggregate units for analysis. In ERA, a two-digit unit of evaluation is constructed from the articles located in the four-digit codes which sit within that two-digit code.

For this Discussion Paper, an RCI is calculated for the set of articles identified through the text mining exercise at the four-digit Group code level. In other words, after text mining has been applied, articles are grouped together based on their four-digit FoR code, and an RCI is calculated for each Group. This represents the average weighted citation performance of the Group against the world average citation performance. The result is an indication of performance benchmarked to a world standard.

To demonstrate the breadth of this performance and to potentially identify if a Group RCI is being driven by a small number of highly cited articles, an RCI Class Distribution is provided for each four-digit Group. This illustrates the spread of the citation performance of the Group.

Specialisation Index

The Specialisation Index (SI) can be used to describe a FoR Group in terms of the extent to which Australia is 'specialised' relative to the rest of the world in that discipline. The SI is an indicator of research intensity in a particular discipline, compared with the overall research effort in all disciplines. In this Discussion Paper, it is intended to show where Australia might have a comparative advantage in terms of research focus to particular areas of research.

The SI is calculated by comparing the share of all published articles in the ERA dataset which are assigned to a four-digit FoR with the share of all articles for the world[13] in that same FoR. An index value of greater than

[12]As outputs in ERA can be apportioned up to three FoR codes, citation performance is also apportioned so that an article which has more than one four-digit FoR code assigned can have different RCI results at the article level due to the different FoR code benchmarks it is compared against.

[13]For the purposes of this Report, 'world' refers to papers published in journals that appear on the ERA 2012 Journal List, and which appear in the Scopus dataset as article types 'journal article', 'conference article' and 'review'.

0 would mean that Australia is specialised relative to the world in a discipline, whereas an index value below 0 would mean that Australia has less of a focus in that field relative to the rest of the world (see Appendix F: Specialisation Index).

In this Discussion Paper, an SI is calculated for four-digit FoRs nationally that underpin RETechs. This may be useful in looking at the sustainability of RET research, potential for growth and/or where there are opportunities for further investment. The SI is a potential guide to policy decisions about support for particular research activities. When considering the SI of the underpinning disciplines, it is also important to consider the proportion of the discipline which is conducted in RETechs (i.e. those articles identified through the text mining exercise as being within a particular FoR).

Combining the Performance Measures

The individual measures used in this study may be sufficient to inform policy decisions, but the combined information presented by the RCI, the SI and the volume of RETechs research gives a rich picture of the performance and context of RETechs research in Australian universities. So for example, a discipline which is comparatively specialised in Australia might nonetheless perform poorly in citing terms relative to the rest of the world; alternatively high performing RETechs research may not be supported by a robust underlying research discipline. Each situation will have an appropriate policy response.

Classification of research

An objective of this Discussion Paper is to provide ARENA with a list of potential priority research areas for support. To achieve this, the ARC has applied a number of statistical tests to the sets of documents identified through text mining in order to (i) group them appropriately and (ii) characterise these groups in terms of particular RETechs research. This allows for discrete areas of research to be identified and mapped to the research activity in Australia's universities and CSIRO, and for these groups to be characterised by key terms extracted from the research articles themselves. This also overcomes the limitations of keywords as a way of describing the research effort.

Two methods are used to group documents in this Discussion Paper.

Correspondence analysis

Correspondence analysis (CA) is a statistical method used to explore the relationships between categorical data contained in tables (i.e. between rows and columns of 0 and 1 values). It is designed to assign order between categorical variables to draw out the relationships between them. In this instance, the university and CSIRO research publications are tabulated against the range of terms within them.

The group is transformed into a term document matrix or table, where all of the documents in the set are tabulated against each term in the set. The statistical distance between each document can then be calculated. See Appendix G: Correspondence Analysis and Hierarchical Clustering.

Hierarchical Clustering

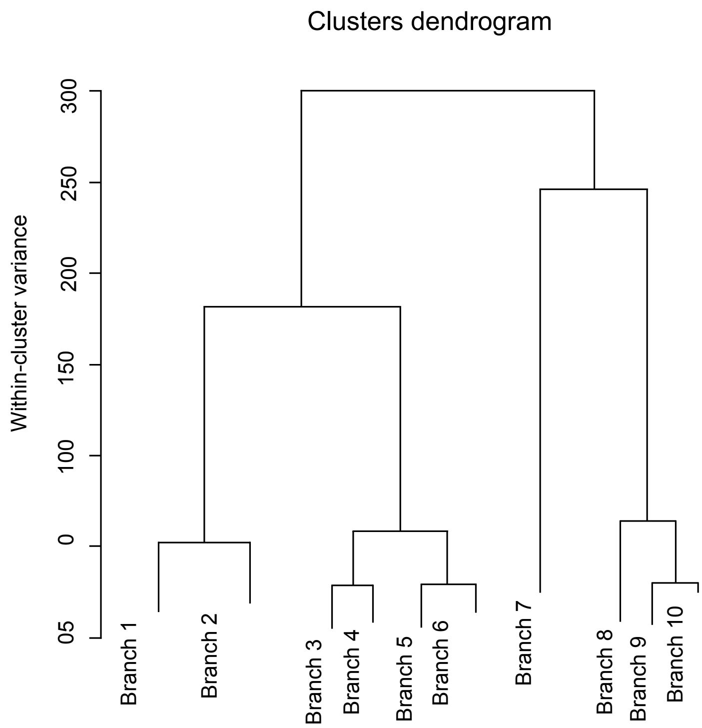
Hierarchical clustering is a statistical method used to summarise the relationship between data points on their similarities (in this case using the results of correspondence analysis). This Discussion Paper uses a form of clustering called 'complete link' clustering whereby each research output begins as an individual cluster. These are progressively combined into larger clusters based on the distance between their individual components. Each stage of the clustering process combines the two closest clusters into a new cluster. This process continues until the entire set is merged into a single cluster.

Clustering is normally visualised as a dendrogram as in the following example:

Each merge is represented by a node connecting two clusters and the y axis is the measure of similarity at which point the two clusters are merged. The height of the node is the equivalent of the distance value between the two clusters. The most similar clusters will have a low distance value and so will merge most quickly (i.e. the vertical lines before the node will be shortest). The decision of how many clusters to retain is made by close examination of the resulting data.

The purpose of correspondence analysis and hierarchical clustering is to draw out patterns of relationships between the raw documents being analysed which would not be obvious from the data.

Figure 3 Example dendrogram



Section Two

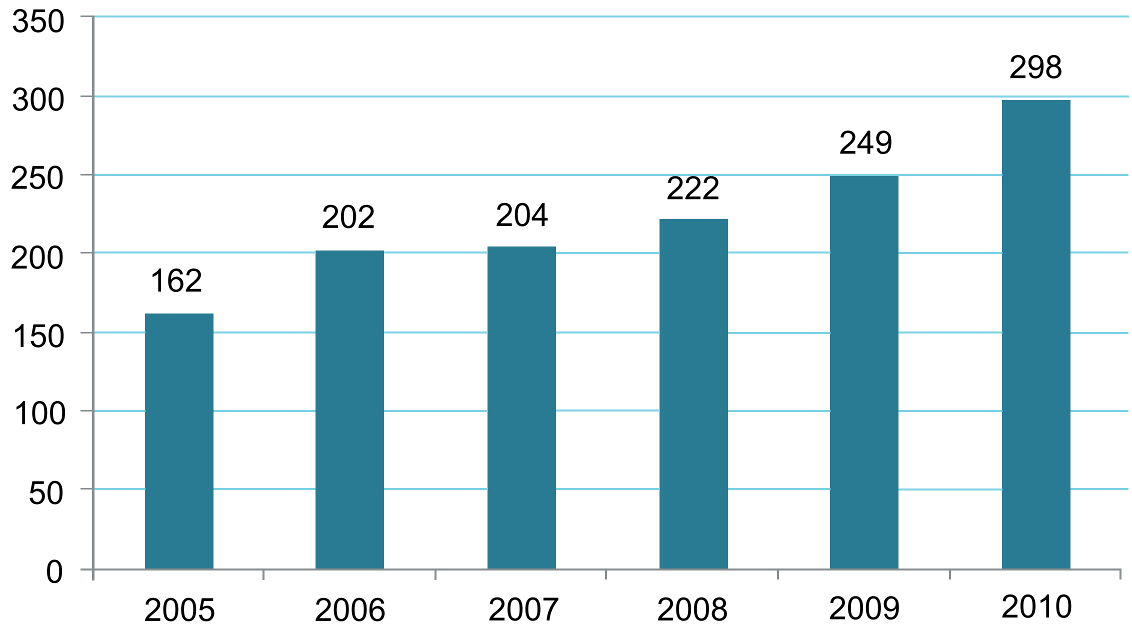
Identifying and Describing Renewable Energy Technologies

Keyword matching

To establish a dataset for further analysis, the ARC undertook keyword searching to identify journal articles that were considered relevant to RETechs. ARENA provided the ARC with keywords which cover the spectrum of RETechs. The keywords were used to search the Scopus world data, identifying articles that were (i) published by universities (as matched through ERA data), and/or (ii) published by CSIRO, and (iii) matched against one or more of the keywords. This initial dataset included a large number of 'false-positives' because the ranking algorithm attributes a rank to any match with the keywords. To remove these from the dataset, manual checks were conducted by members of the ARENA team who identified a threshold at which the ranks assigned were identifying relevant results, while filtering out irrelevant ones. In total, this process identified 1 337 unique articles which were directly relevant to ARENA's keywords. Of these, 905 were attributed to universities, 366 to the CSIRO and 66 articles that were attributed to both a university and CSIRO. This represents around 1-3%[14] of the universities' and the CSIRO's research articles in total for the period.

The results of the keyword matching are provided in Figure 4 which shows the number of unique research articles that matched against the keywords across the reference period, 2005-2010.

Figure 4 Number of RETechs publications by year



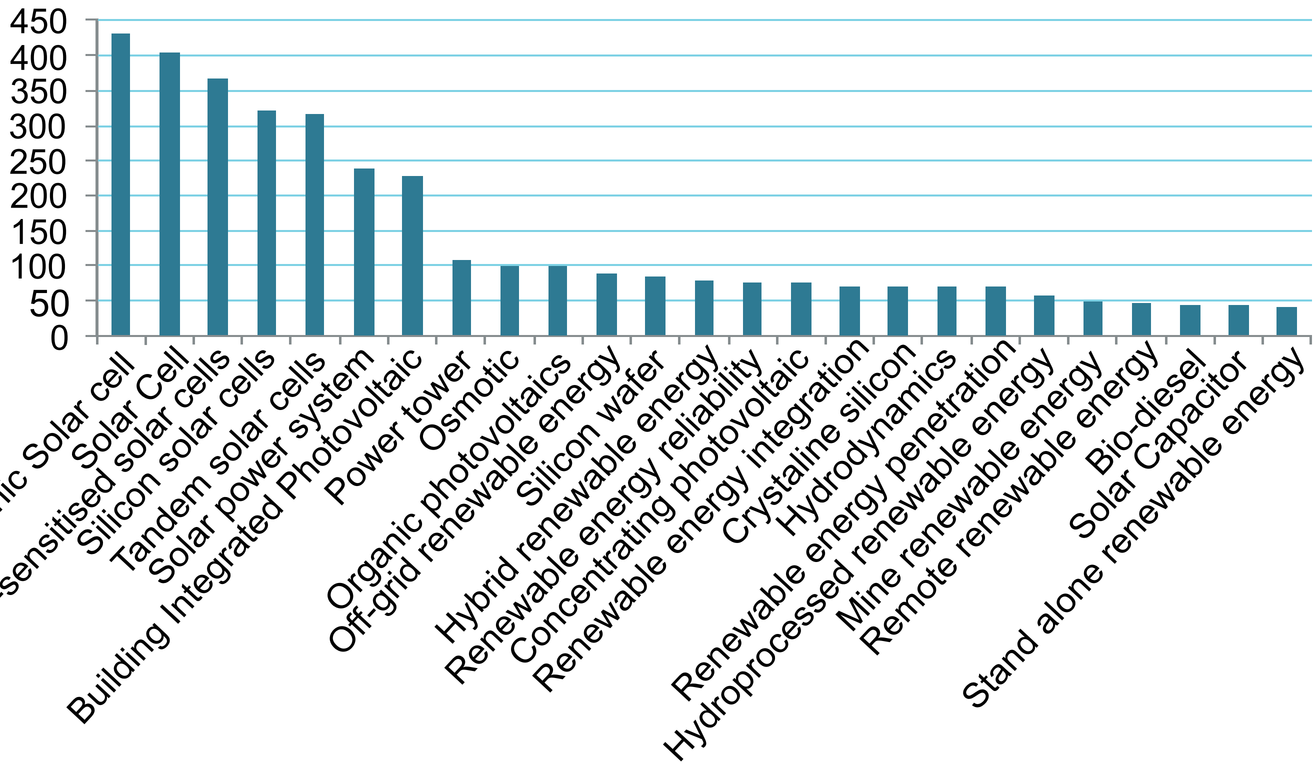
[14]Based on the total number of indexed journal articles attributed to CSIRO and Australian universities contained identified in the Scopus custom world dataset.

There is a steady increase across the reference period from 162 in 2005 to 298 in 2010 at an average annual growth of 13%.

Figure 5 shows how these results were distributed across the top 25 matched keywords that were searched.[15]

It is clear from Figure 5 that there is a higher incidence of matches against search terms related to 'solar cells' than any of the other keywords. This might be an effect of the keyword matching, or evidence of a higher concentration of work into this particular RETech.[16]

Figure 5 RETechs publications by top 25 ARENA keywords matches



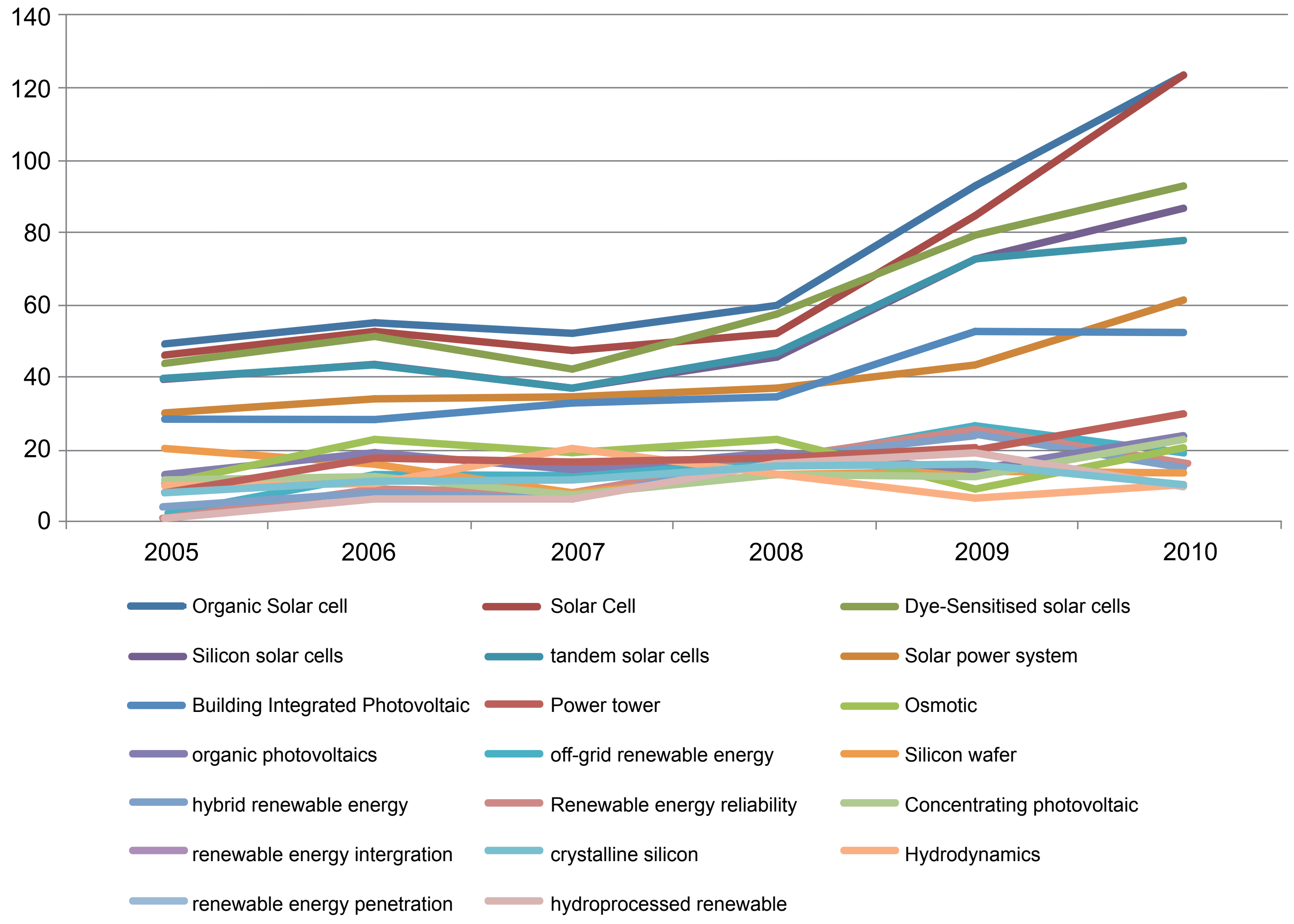
[15] *The matching results include where a single article may have matched against multiple of the search terms. It should also be noted that this is partial word matching, so, for example, the phrase 'mine renewable energy' matched more often articles written on 'luminescence' ('lu – mine - scence') that also included the terms 'renewable' and 'energy' in them, than it did the exact phrase 'mine renewable energy'. Similarly 'off-grid renewable energy' more often matched with articles about 'grid connected wind' power. Section Four: Classifying RETechs Research provides ways around the limitations of keyword searching.*

[16] *This is explored in more depth in Section Four: Classifying RETechs Research which provides the results of the correspondence and cluster analyses.*

Figure 6 provides trend data for the keywords that matched more than 50 research articles across the reference period. Again, it illustrates a prominence of 'solar cell' keywords in the results.

At between 1-3%[17] of all research articles, RETechs research would appear to be a relatively small focus of activity. However, this may be due to the multi-disciplinary nature of RETechs research: in contrast to, for example, Organic Chemistry, which describes an agreed research methodology, RETechs research is diffuse in disciplinary makeup.

Figure 6 RETechs publications by keyword for reference period



[17] *The RETechs research comprises around 1% of the university data searched, and around 3% of the CSIRO data searched.*

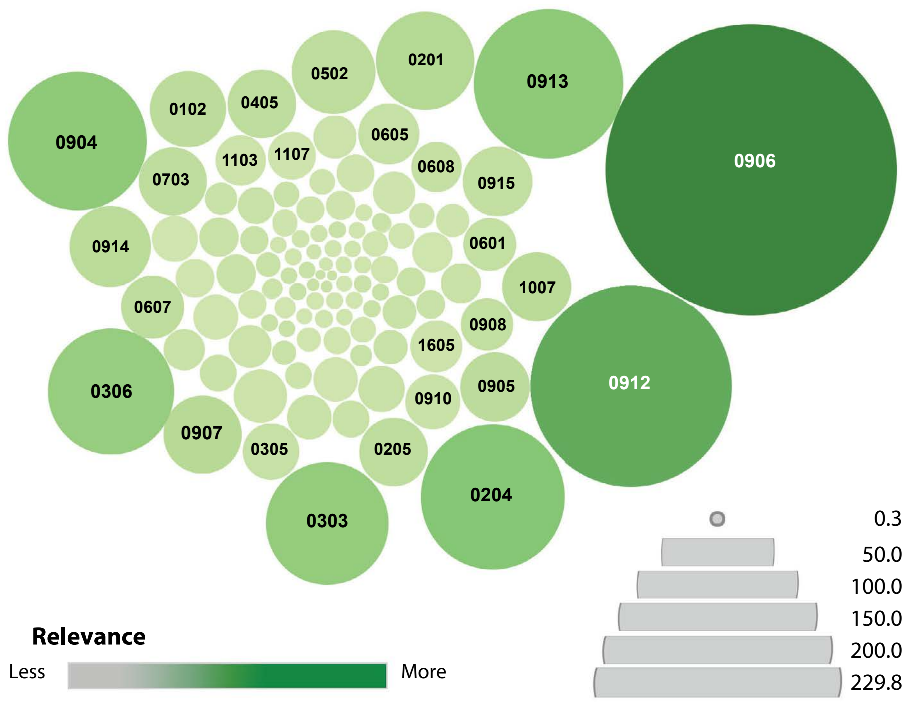
Figure 7 shows the disciplinary makeup of the RETechs research articles attributed to universities as they are assigned to four-digit FoR codes in the ERA dataset. The size of each circle represents the relative number of research articles which are coded to the four-digit FoR, and the colour gradient represents the summed rank of the articles against the keywords which can be considered a proxy for relevance.

The FoR code '0906 Electrical and Electronic Engineering' returned both the largest number of relevant journal articles (230) and those articles had the highest combined relevance to the keywords.

Other notable FoR codes include:

- 0912 Materials Engineering
- 0913 Mechanical Engineering
- 0204 Condensed Matter Physics
- 0904 Chemical Engineering
- 0303 Macromolecular and Materials Chemistry
- 0306 Physical Chemistry (including Structural Chemistry)

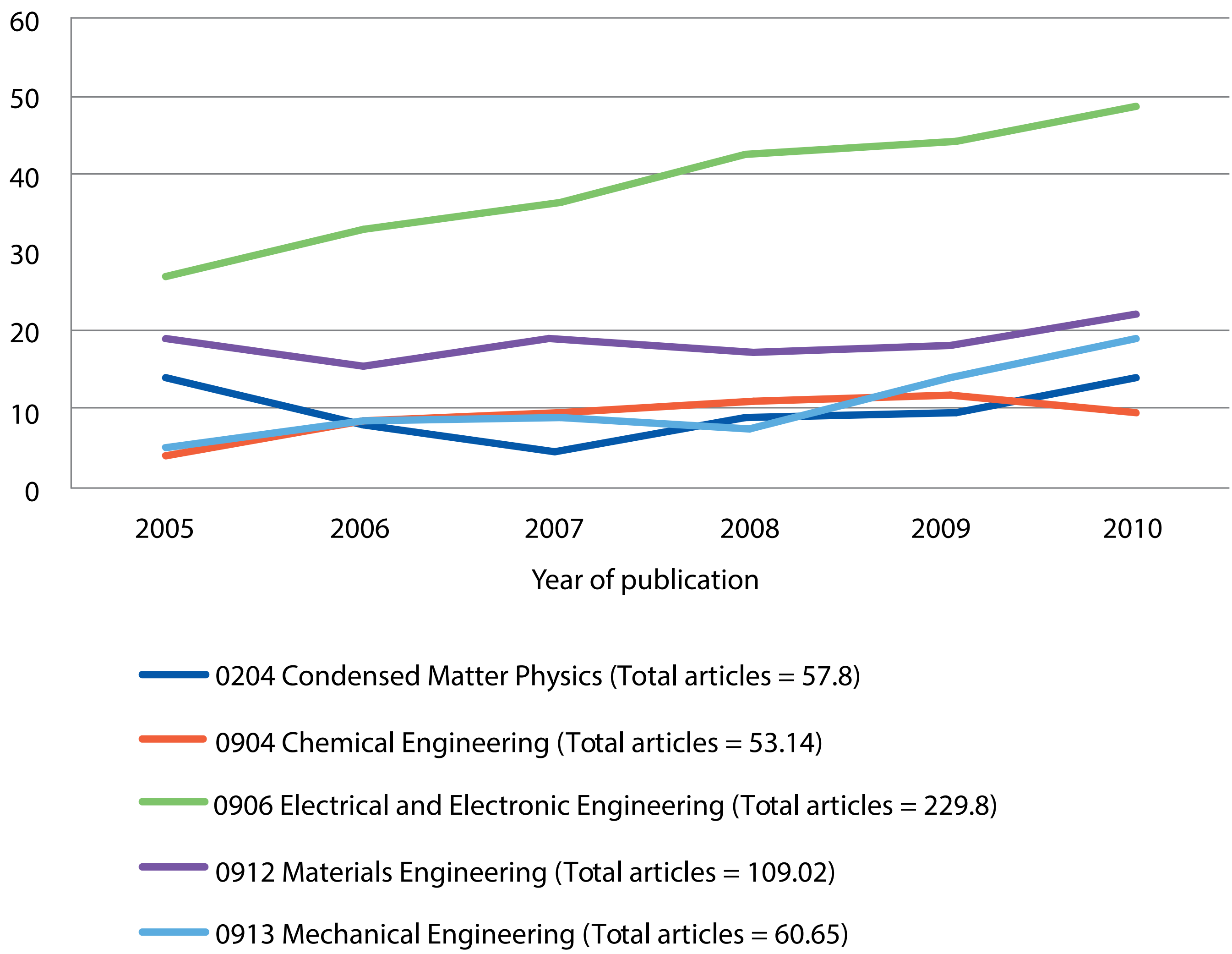
Figure 7 University RETechs publications by FoR[18]



[18]The top five FoRs which support RETechs research are described in detail below. A list of all FoR codes presented in Figure 7 is provided in Appendix H:FoR codes identified with RETechs Publications

Figure 8 shows the trend of the RETechs research articles in the underpinning disciplines where there were more than 50 articles across the reference period. These disciplines account for approximately half of the total university-based articles that were identified as relevant to the keywords.

Figure 8 University RETechs publications by top five FoRs for reference period



There is a consistent level of RETechs research articles within these disciplines over the period. The notable discipline here is ‘0906 Electrical and Electronic Engineering’ where the number of articles is high throughout the period and increasing far more than the other FoRs throughout the period.

It is clear that rather than describing a set of well-established methods (as does, for example, Organic Chemistry), RETechs research involves the application of multiple methodologies. Table 3 presents ERA 2012 data for similarly applied, multi-disciplinary four-digit FoR codes in and around the broad fields of Engineering and Technology:

Table 3 Total ERA 2012 outputs for select multidisciplinary and applied disciplines

FoR name	Total outputs (2005-2010)
Aerospace engineering	765
Automotive engineering	572
Manufacturing engineering	996
Industrial biotechnology	166
Agricultural biotechnology	277

Viewed in this context, 1 337 articles published in the reference period is a reasonable level of output.

The Top Five Disciplines which support RETs Research

It is important to understand both the context and quality of the four-digit FoR codes that contribute to RETechs research. These disciplines underpin work into RETechs and it is logical that the sustainability and quality of these disciplines will have significant bearing on the health of the RETechs research. Each FoR code is described in detail below (in order of their FoR code) in terms of research volume and quality performance in the ERA 2010 and 2012 rounds.[19]

0204 Condensed Matter Physics

Condensed Matter Physics research investigates the physical properties of condensed phases of matter (for example solids, liquids and superconducting phases). Its underlying six-digit fields are:

020401 Condensed matter characterisation technique development

020402 Condensed matter imaging

020403 Condensed matter modelling and density functional theory

020404 Electronic and magnetic properties of condensed matter; Superconductivity

020405 Soft condensed matter

020406 Surfaces and structural properties of condensed matter

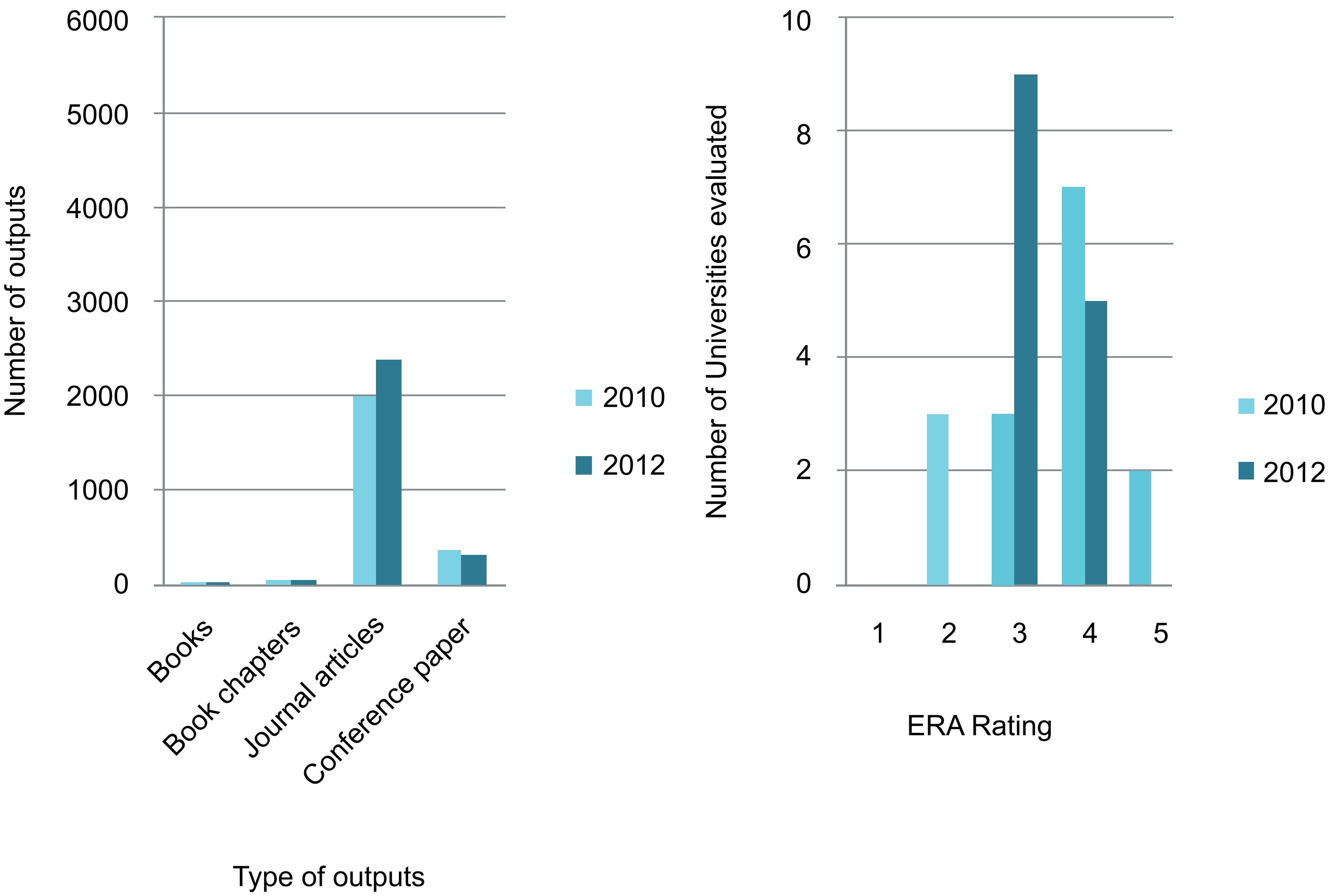
020499 Condensed matter physics not elsewhere classified

In ERA 2012 there was a total of 182 full-time equivalent research staff employed in the higher education sector in the discipline. While the number of universities undertaking sufficient research to be assessed dropped by one nationally from the ERA 2010 round, the 14 universities that were assessed in ERA 2012 were all performing world standard research or higher.

The following is a summary of this FoR in ERA 2010 and 2012:

[19] *All data are taken from the ERA 2010 National Report and the ERA 2012 National Report.*

Figure 9 Condensed Matter Physics in ERA 2010 and ERA 2012



0904 Chemical Engineering

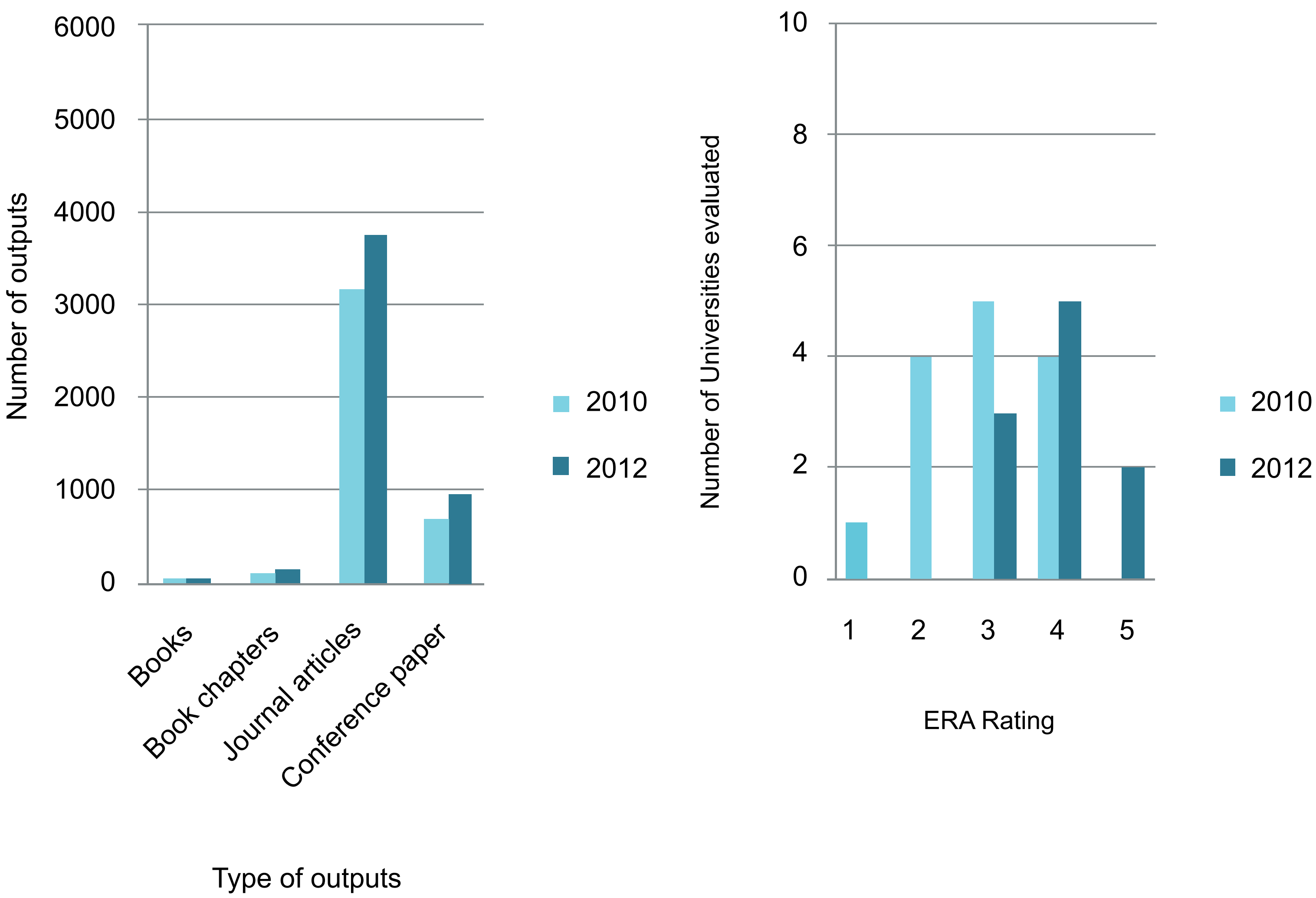
Chemical Engineering is a field that researches the properties of raw materials and develops equipment to change the raw materials into more valuable (and potentially commercial) forms. Included in this field is research into renewable fuels. Its underlying six-digit fields are:

- 090401 Carbon capture engineering (excluding sequestration)
- 090402 Catalytic process engineering
- 090403 Chemical engineering design
- 090404 Membrane and separation technologies
- 090405 Non-automotive combustion and fuel engineering (including alternative and renewable fuels)
- 090406 Powder and particle technology
- 090407 Process control and simulation
- 090408 Rheology
- 090409 Wastewater treatment processes
- 090410 Water treatment processes
- 090499 Chemical engineering not elsewhere classified

In ERA 2012 there was a total of 289 full-time equivalent research staff employed in the higher education sector in the discipline. Ten universities produced sufficient output over the ERA threshold to be evaluated in ERA 2012, a reduction of four from the previous round. However there has been a significant increase in the performance of these units, increasing from 64 per cent in ERA 2010 to 100 per cent in ERA 2012 performing at world standard research or higher.

The following is a summary of this FoR in ERA 2010 and 2012:

Figure 10 Chemical Engineering in ERA 2010 and ERA 2012



0906 Electrical and Electronic Engineering

This FoR includes research into the generation, transmission and distribution of electricity, electronics and electromagnetism. Its underlying six-digit fields are:

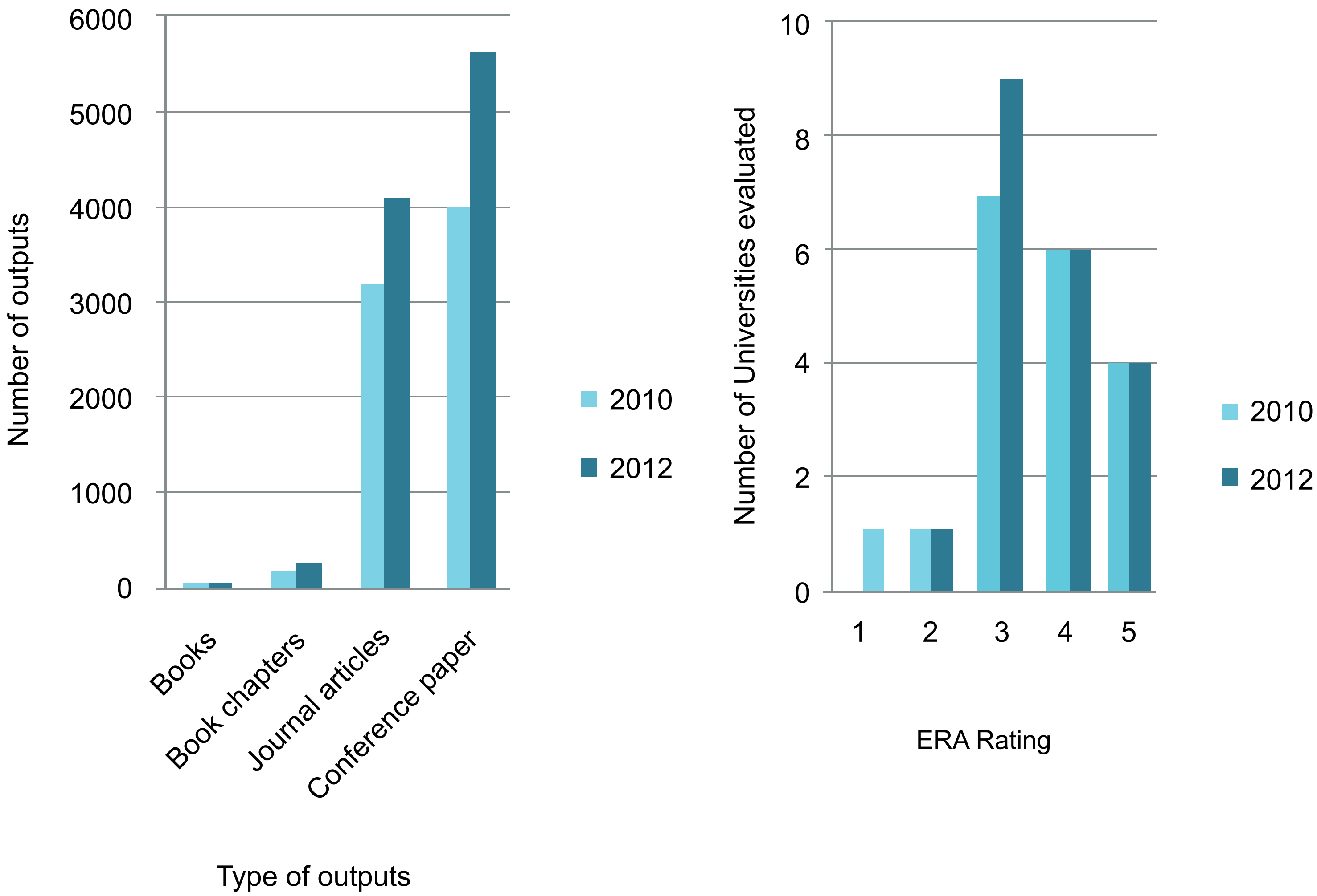
- 090601 Circuits and systems
- 090602 Control systems, robotics and automation
- 090603 Industrial electronics
- 090604 Microelectronics and integrated circuits
- 090605 Photodetectors, optical sensors and solar cells
- 090606 Photonics and electro-optical engineering (excl. communications)
- 090607 Power and energy systems engineering (excl. renewable power)
- 090608 Renewable power and energy systems engineering (excluding solar cells)
- 090609 Signal processing
- 090699 Electrical and electronic engineering not elsewhere classified

Electrical and Electronic Engineering is significant within the overall Engineering research activity of Australia's universities both in terms of inputs such as researchers who are engaged in the Group and income from various sources, as well as in the quality of work.

In ERA 2012 there was a total of 483.7 full-time equivalent research staff employed in the higher education sector in the discipline and more than $150m reported research income. A total of 9 890 research outputs were produced over the ERA 2012 reference period which is a significant increase on the 2010 ERA evaluation round. Twenty-one universities produced sufficient output over the ERA threshold to be evaluated in ERA 2012, and 90 per cent of those were judged to be performing world standard or higher research which was an increase on the results from the 2010 ERA round.

The following is a summary of this FoR in ERA 2010 and 2012:

Figure 11 Electrical and Electronic Engineering in ERA 2010 and ERA 2012



0912 Materials Engineering

Materials Engineering investigates the relationship between the structure of materials at the molecular level and its observable properties. Materials engineers can work to improve existing materials or create new ones. Three of the subfields conduct research into semiconductors which might include work of significance for solar cells. Its underlying six-digit fields are:

091201 Ceramics

091202 Composite and hybrid materials

091203 Compound semiconductors

091204 Elemental semiconductors

091205 Functional materials

091206 Glass

091207 Metals and Alloy materials

091208 Organic semiconductors

091209 Polymers and plastics

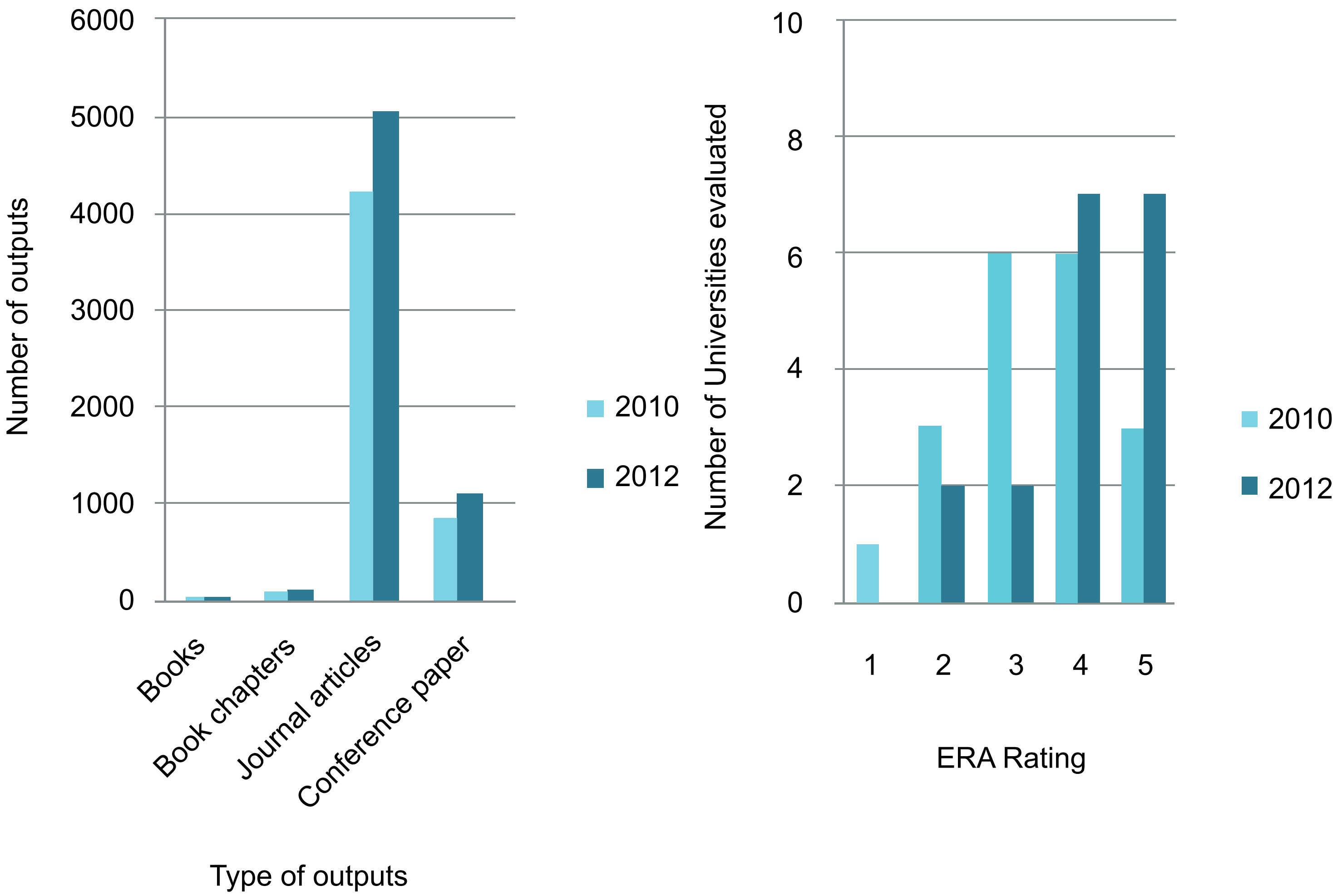
091210 Timber, pulp and paper

091299 Materials engineering not elsewhere classified

Materials Engineering is also significant within the overall Engineering research activity of Australia's universities. In ERA 2012 there was a total of 345.3 full-time equivalent research staff employed in the higher education sector in the discipline and more than $120m reported research income. A total of 6 318 research outputs were produced over the ERA 2012 reference period. Eighteen universities produced sufficient output over the ERA threshold to be evaluated in ERA 2012, and 89 per cent of those were judged to be performing world standard or higher research. This was a noticeable shift upwards in quality on the results from the 2010 ERA round.

The following is a summary of this FoR in ERA 2010 and 2012:

Figure 12 Materials Engineering in ERA 2010 and ERA 2012



0913 Mechanical Engineering

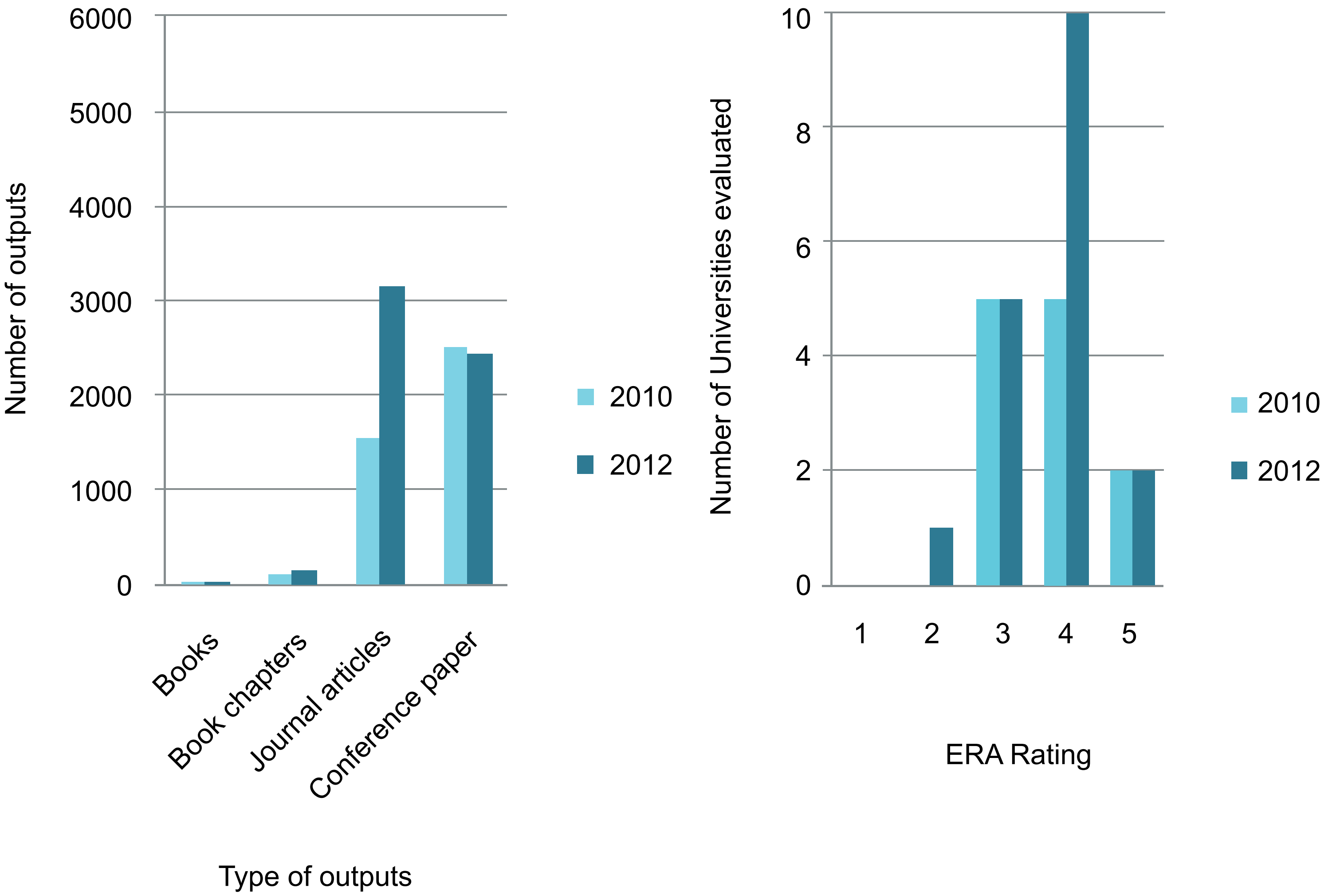
Mechanical Engineering uses engineering, physics and materials engineering for research into mechanical systems. Energy generation, conversion and storage is a key subfield. Its underlying six-digit fields are:

- 091301 Acoustics and noise control (excluding architectural acoustics)
- 091302 Automation and control engineering
- 091303 Autonomous vehicles
- 091304 Dynamics, vibration and vibration control
- 091305 Energy generation, conversion and storage engineering
- 091306 Micro electromechanical systems (MEMS)
- 091307 Numerical modelling and mechanical characterisation
- 091308 Solid mechanics
- 091309 Tribology
- 091399 Mechanical engineering not elsewhere classified

In ERA 2012 there was a total of 345 full-time equivalent research staff employed in the higher education sector in the discipline. Eighteen universities produced sufficient output over the ERA threshold to be evaluated in ERA 2012, and 94 per cent of those were judged to be performing world standard or higher research.

The following is a summary of this FoR in ERA 2010 and 2012:

Figure 13 Mechanical Engineering in ERA 2010 and ERA 2012



Summary

The research into RETechs is underpinned by a small number of disciplines, mainly within the two-digit Division of Engineering. Research into Electrical and Electronic Engineering, Materials Engineering, Chemical Engineering and Mechanical Engineering are significant contributors to RETechs research in Australian universities. In addition, a significant proportion of the work is conducted in Condensed Matter Physics. These disciplines account for more than 50% of the work into RETechs and are the only disciplines that sustain research activity of more than 50 journal articles across the reference period.

In all cases, the research activity in these disciplines is growing as indicated by the increasing numbers of publications reported between ERA 2010 and ERA 2012. The overall quality of each discipline is also improving over time, with larger proportions of the universities that are active in these disciplines judged to be performing research at world standard or higher in 2012 than 2010. This indicates a strong set of research disciplines underpinning Australian universities' R&D into RETechs, and that over time this is increasing in terms of size and quality.

Section Three

Relative Citation Impact and Specialisation Index

Selection of the top five Field of Research codes

To more closely examine the performance of RETechs research, this section provides a range of bibliometric indicators for both the disciplines that underpin RETechs, as well as the set of RETechs articles identified through text mining. This allows conclusions to be drawn about the relative quality of the RETechs research being undertaken in Australian universities.

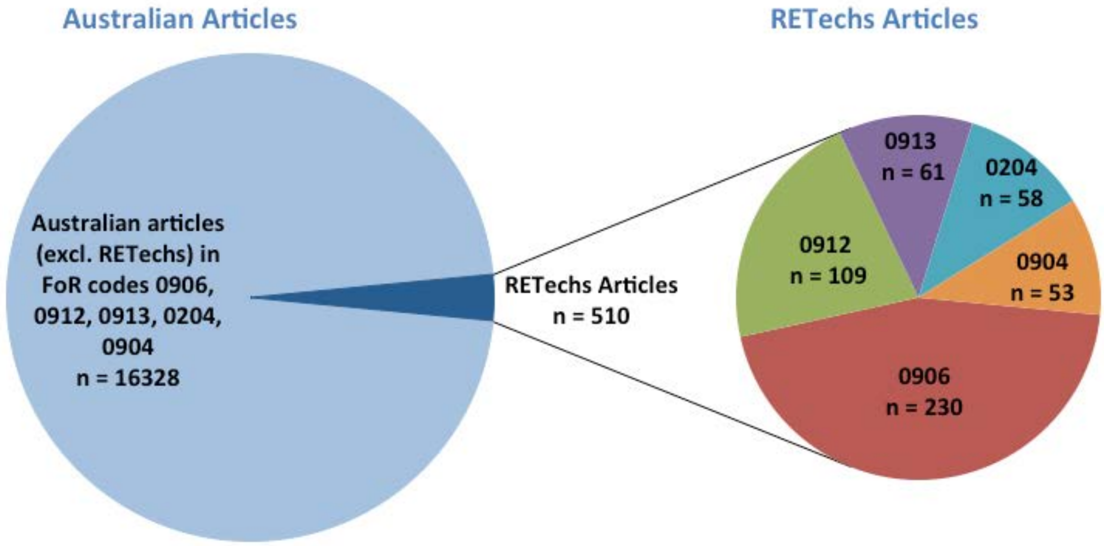
As in Section Two: Identifying and Describing Renewable Energy Technologies, the focus of this analysis is those four-digit FoR Groups where there is sufficient volume to generate bibliometric indicators i.e. more than 50 journal articles across the reference period. This is broadly in line with a notion of 'research-activity' from the ERA evaluation framework; below this threshold it is difficult to identify a sustained research effort. Table 4 outlines the disciplines under consideration in this section.

The RETechs articles represent a relatively small proportion of the total Australian output from these five codes.

Table 4 Top 5 FoRs containing RETechs research

Four-digit FoR code	Code name	Number of RETs articles identified through text mining
0906	Electrical and Electronic Engineering	229.8
0912	Materials Engineering	109
0913	Mechanical Engineering	60.6
0204	Condensed Matter Physics	57.8
0904	Chemical Engineering	53.1

Figure 14 Renewable energy articles compared to total Australian articles



A total of 16 838.8 Australian articles were submitted within these five FoR codes in ERA 2012. Of these, 3% (510.4) apportioned articles were identified as RETechs research.

These articles were coded within:

- 0906 Electrical and Electronic Engineering (45%)
- 0912 Materials Engineering (21%)
- 0913 Mechanical Engineering (12%)
- 0204 Condensed Matter Physics (11%)
- 0904 Chemical Engineering (10%)

Relative Citation Impact for RETs articles

The RCI[20] measures citation performance against a discipline specific and year specific citation benchmark. It gives an indication of the relative citation performance of an article or group of articles against a normalised world citation average. RCIs were calculated for the five underpinning four-digit FoR codes, and separately for the set of RETechs research articles within these. This allows for the RETechs research to be compared against both the Australian average for the underpinning discipline, and the world average for the underpinning discipline. The results are presented in Figure 15.

[20] *The method for constructing the ERA Relative Citation Index (RCI) and RCI Classes is described in more detail in Appendix E: Citation Benchmark Methodology.*

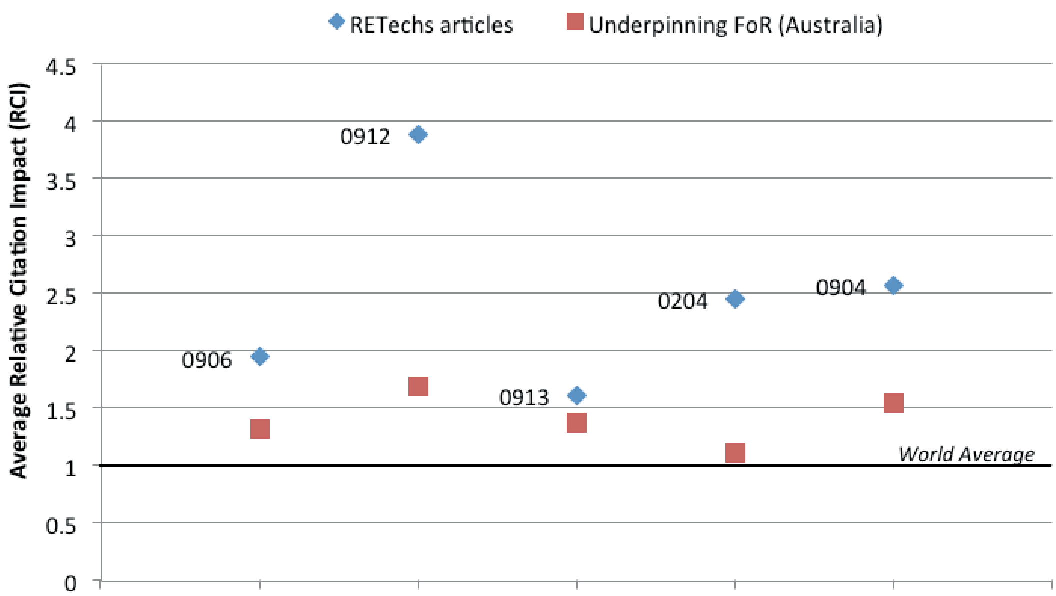
All five underpinning disciplines have an average citation performance above the world average (ranging from '0204 Condensed Matter Physics' at 1.1 to '0912 Materials Engineering' at 1.7 times the world average).

In each instance the RETechs research exceeds both the world average performance and the average performance of the underpinning FoRs. The articles located in '0912 Materials Engineering' demonstrate particularly outstanding citation performance, with an RCI of 3.9 times the world average. This means that on average the 109 RETechs articles produced in Materials Engineering receive 3.9 times the number of citations as the average paper in the world dataset. The RCIs of the others, too, are very high, ranging from '0913 Mechanical Engineering' at 1.6 to '0904 Chemical Engineering' at 2.6. In all, RETechs form very high performing pockets within high performing underpinning disciplines based on this average citation indicator.

A more fine-grained measure of the citation performance of the RETechs articles can be provided by allocating the RCI of individual articles into RCI Classes. The RCI Classes indicate how distributed the performance of the RETechs articles is.[21] To do this, the individual RETechs articles are distributed amongst seven classes of RCI as per the ERA citation methodology: Class 0 output with no citations (RCI=0); Class I is output with RCI ranging from 0 to 0.79; Class II is output with RCI ranging from 0.8 to 1.19; Class III is output with RCI ranging from 1.2 to 1.99; Class IV is output with RCI ranging from 2.0 to 3.99; Class V is output with RCI ranging from 4.0 to 7.99 and Class VI is output with RCI above >8.0. In this approach, articles in Class III and above are performing above the world average.

The RCI class distribution for RETechs articles across the five underpinning FoRs are shown below.

Figure 15 Average RCI for articles within the top five disciplines



[21] *It accounts for, for example, where the average RCI may be determined by a small number of articles, and therefore where it may not be representative of the whole set.*

Figure 16 RCI Class distribution for articles within Materials Engineering

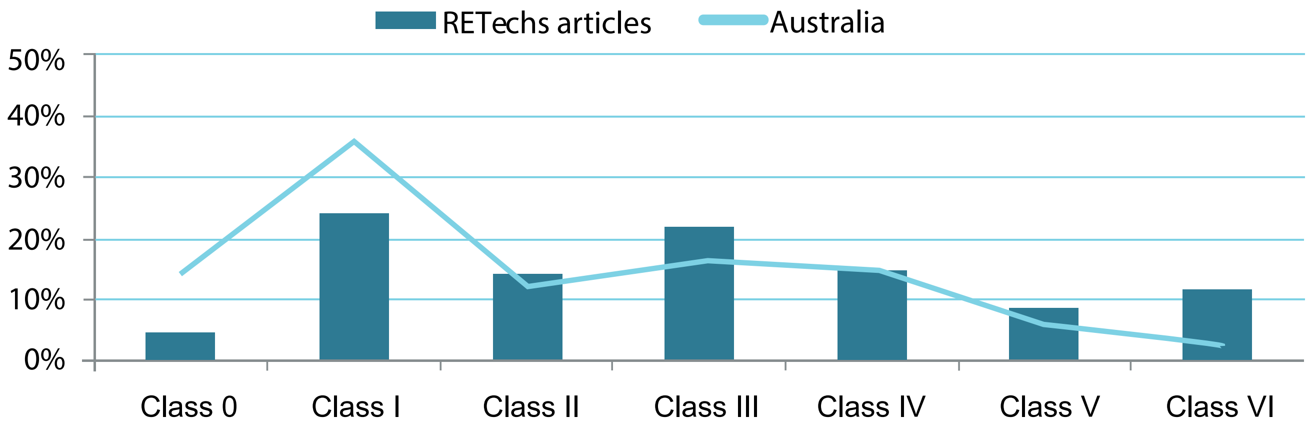


Figure 17 RCI Class distribution for articles within Chemical Engineering

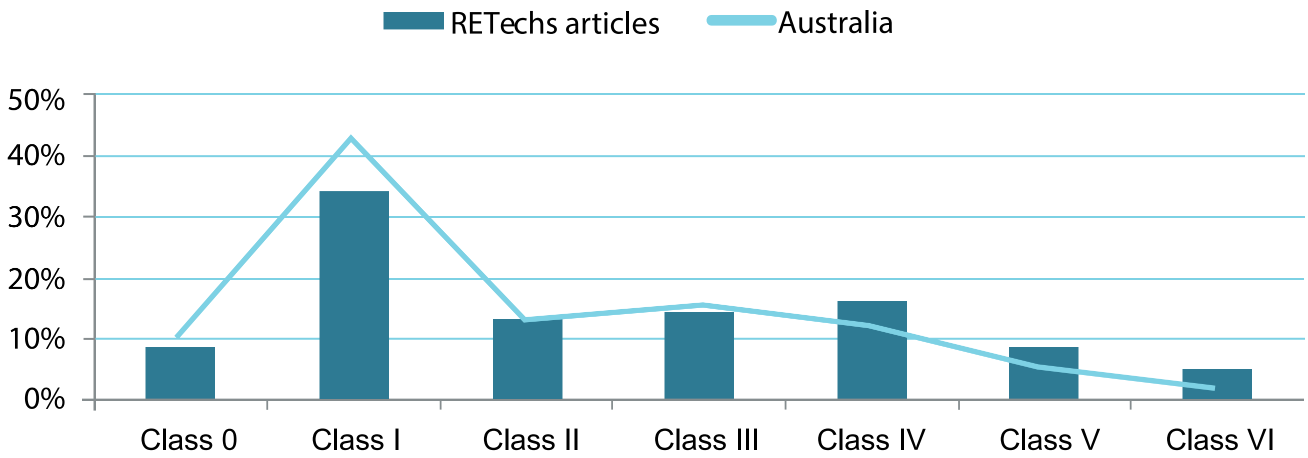


Figure 18 RCI Class distribution for articles within Electrical and Electronic Engineering

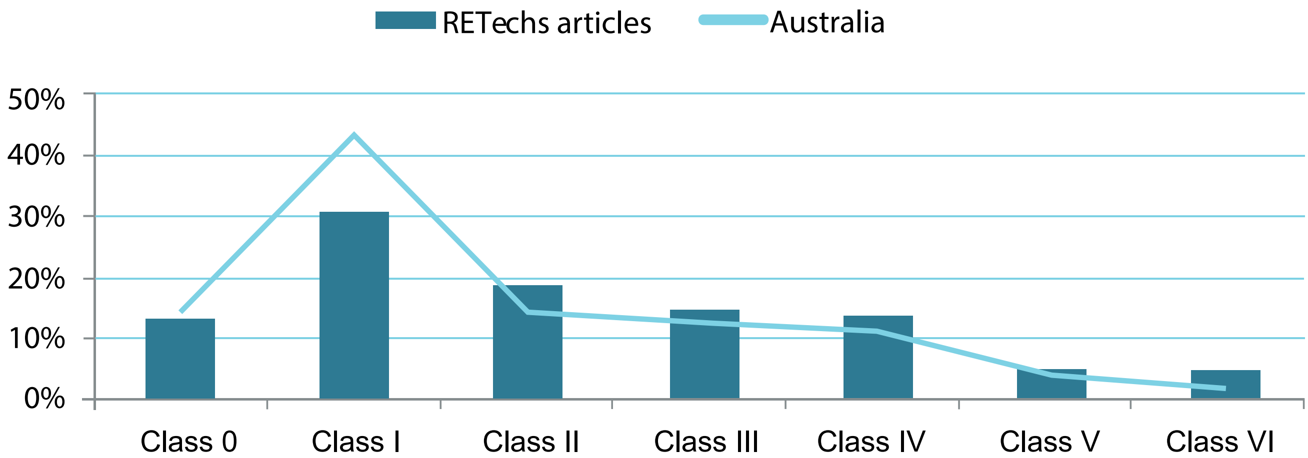


Figure 19 RCI Class distribution for articles within Mechanical Engineering

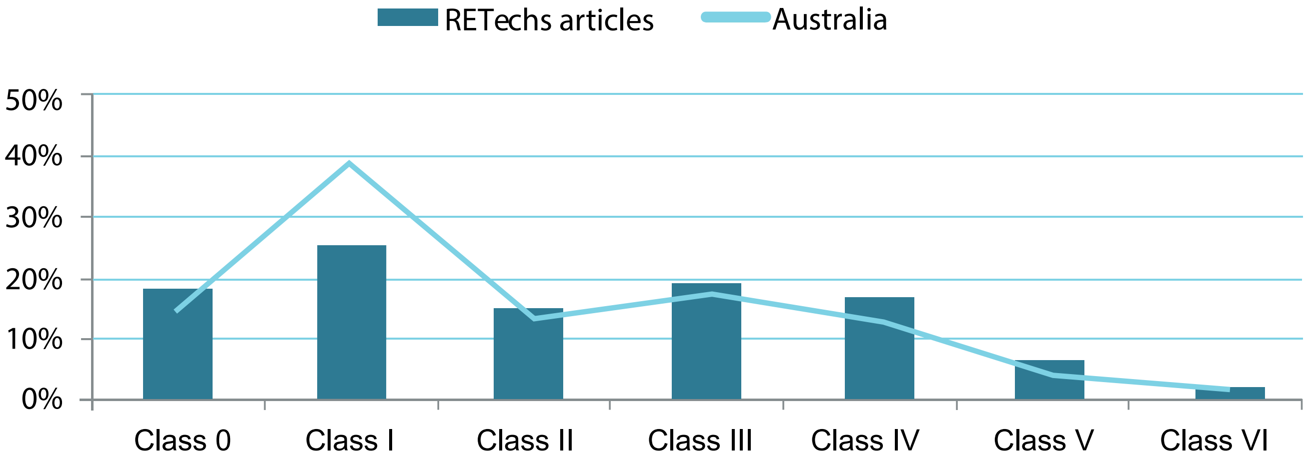
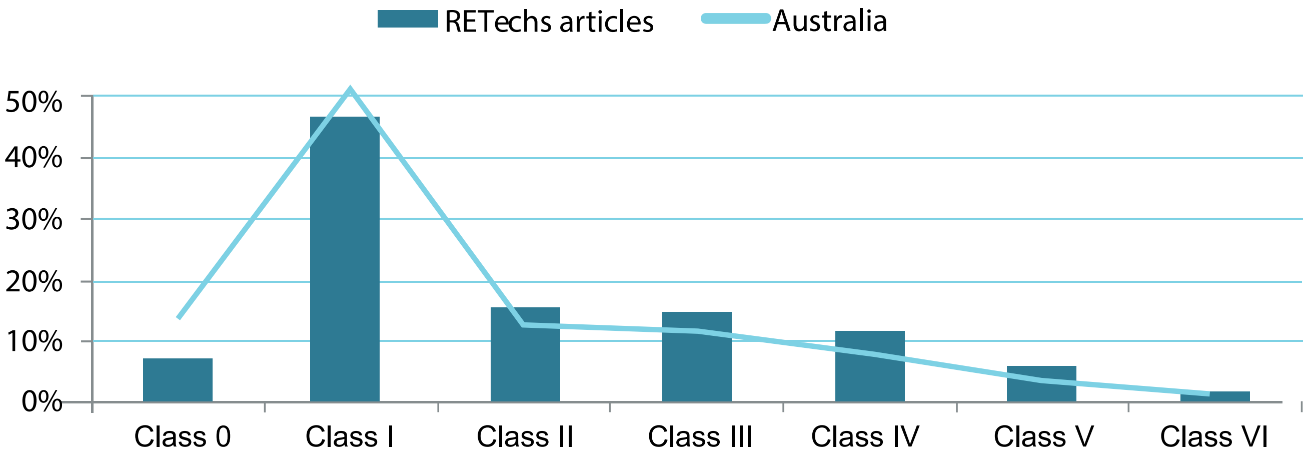


Figure 20 RCI Class distribution for articles within Materials Engineering



The RETechs articles in Materials Engineering are particularly impressive with the number of highly cited articles well above the Australian average especially in Class VI (which is those articles that are cited 8 or more times the world average) and Class V. By contrast, the numbers at the lower end of the scale (no or low citations) are well below the Australian average for Materials Engineering.

The RCI Class distribution is better for the RETechs articles than the Australian average in all cases, especially in the higher Classes (Classes III, IV, V, VI). This supports the data presented in the average RCI, confirming that the average RCI represents a sustained performance above the Australian and world average citation rates and is not skewed by a small number of papers. This provides further evidence of a very high quality pocket of RETechs research supported by high quality underpinning research disciplines.

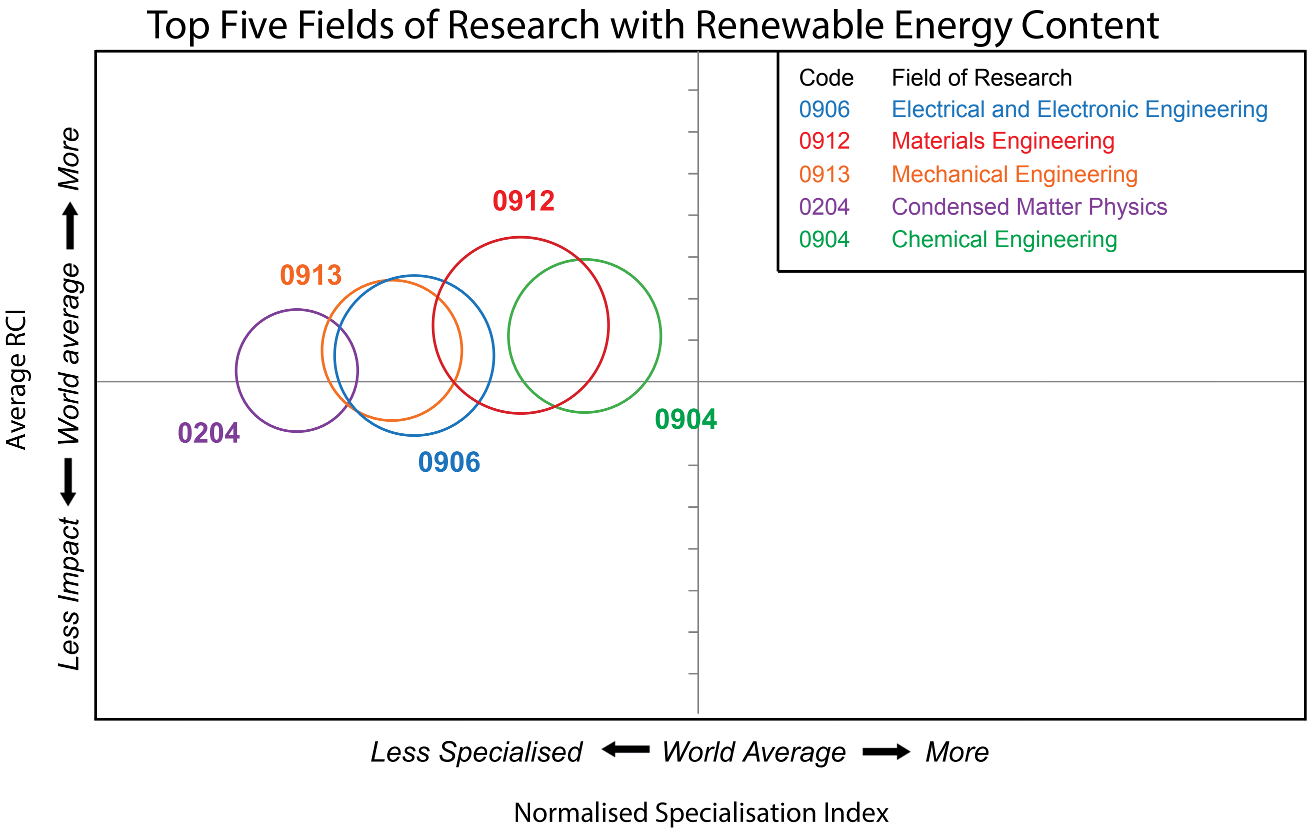
Specialisation Index for RETechs research

The information presented in the RCI is an indication of the broad academic impact for RETechs research and the underpinning discipline. In this sense it is a proxy for research quality. However, research quality is one of a number of useful pieces of information for policy development. To provide further context, a Specialisation Index (SI) is provided below for each of the top five FoR codes underpinning RETechs research in Australia. The SI is an indicator of the research intensity in a given FoR. There are two elements that are considered in the SI: how much of the world's research is undertaken by Australia, and the relative proportions produced by Australia and the world in a particular discipline. If Australia is specialised in a particular discipline, it places more emphasis on that discipline relative to the world at the expense of other research areas (see Appendix F: Specialisation Index).

Figure 21 below shows three dimensions of for each of the five underpinning disciplines: the normalised[22] SI, the RCI and the volume of work produced in Australia. Specialisation in the field is represented along the horizontal axis: when values fall to the right of the axis the FoR is more specialised. The vertical axis maps the average RCI: values above the axis are above the world average for the research field. The area of each circle is proportional to the volume of indexed Australian journal articles.

All five disciplines have low SIs, indicating that Australia does not have a specific focus in these disciplines relative to the world and with reference to the whole research effort. For several disciplines such as '0204 Condensed Matter Physics', '0913 Mechanical Engineering' and '0906 Electrical and Electronic Engineering' Australia has a very low SI. One explanation for this may be that these are well-established research areas in which much of the world is active. This interpretation is supported by the relatively large volume of work that Australia publishes in these disciplines. Figure 22 shows the same FoR-level SIs, but includes the volume and RCI for the RETechs research instead of the underpinning disciplines.

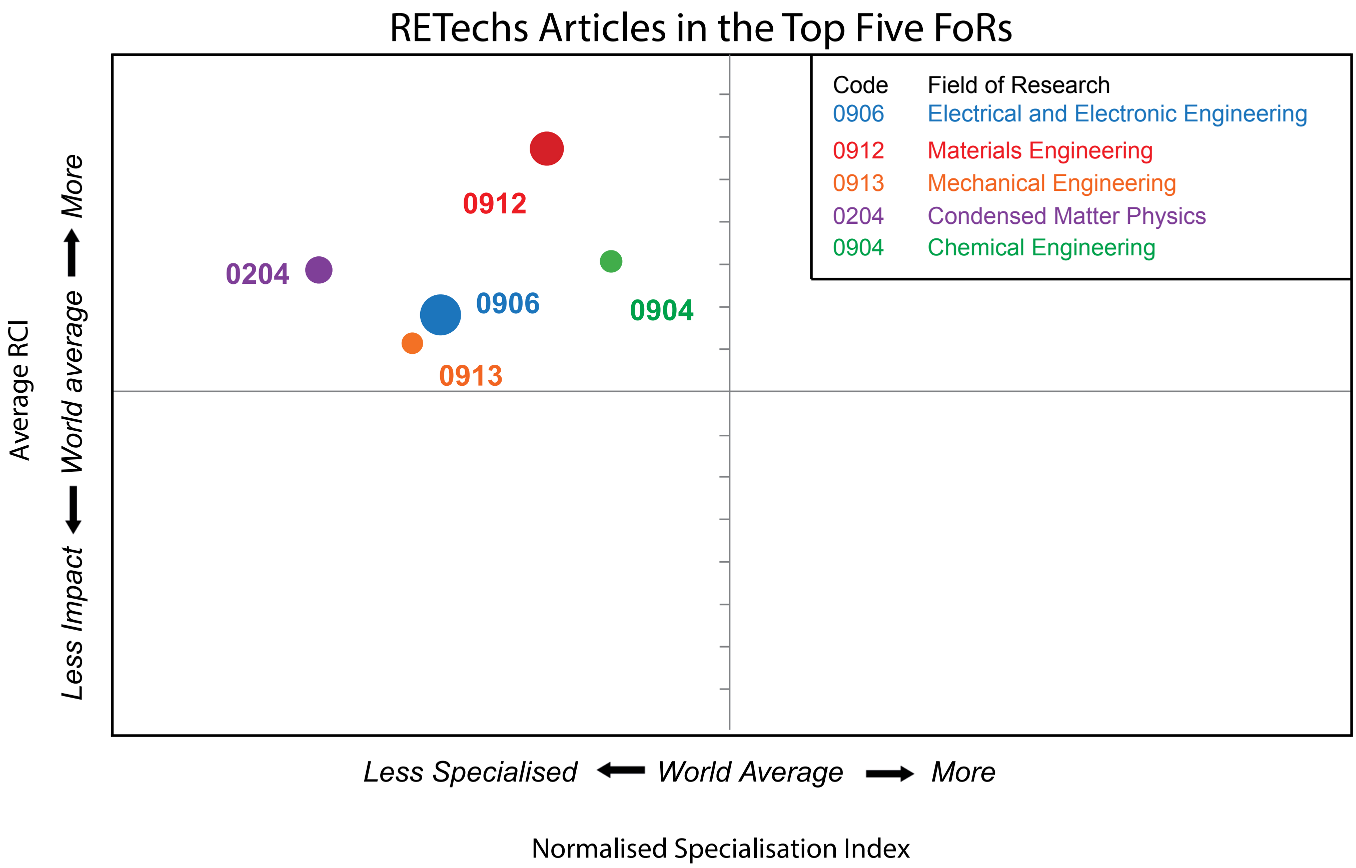
Figure 21 Top five FoRs with renewable energy content by average RCI and Normalised Specialisation Index



[22]To present the SI graphically, the SI was transformed using the hyperbolic tangent of the natural logarithm (TANHln(x)). The resulting values are then evenly distributed between -1 and +1. This transformation has two advantages: it makes the distribution symmetrical on both side of the world average; and it gives more resolution in the area close to the origin where most of the values are located.

As already noted, RETechs research is characterised by being proportionally small but very highly performing. Figure 22 indicates that this performance is done in spite of being (i) proportionally a very small pocket of research, and (ii) contained within underpinning disciplines where Australia does not have a particular specialisation.

Figure 22 Top five FoRs by Average RCI and Normalised Specialisation Index showing proportion of renewable energy articles



Summary

Australian RETechs research has a significant international impact on academic literature. The RCIs indicate that the RETechs research is cited between 1.6 to 3.9 times the world average. This performance is well distributed across the entire set of RETechs articles identified in this Discussion Paper.

The underpinning research disciplines, though not as highly cited, are still characterised by above world average citation rates. This is a very strong research base for the support of RETechs research.

While the SI analysis demonstrates that the underpinning disciplines are well established in Australia, there would appear to be considerable potential for RETechs research within a range of high performing traditional disciplines.

Section Four

CSIRO[23]

CSIRO, the Commonwealth Scientific and Industrial Research Organisation, is Australia's national science agency and one of the largest and most diverse research agencies in the world. CSIRO represents 3% of Australia's research workforce and produces 6% of its research publications. Research is organised into five Groups – Energy; Environment; Food and Life Science Industries; Information Sciences and Manufacturing; Materials and Minerals. Within each Group there are managers of the research capability (CSIRO Divisions) and research execution (CSIRO Flagships).

The CSIRO Mission – "We deliver innovative solutions for industry, society and the environment through great science" – is an important differentiator of CSIRO from the universities in the Australian Innovation System. CSIRO works through mission oriented research projects to provide benefits to Australian industry and the community.

Renewable energy projects are based on the current research capability across the organisation and new capability grown in response to projects with industry clients and government agencies. Research outputs are not just limited to journal publications used in the analysis of this Discussion Paper, but also the intellectual property generated in projects and its further commercialisation to deliver profound impact on Australian society, the environment and the economy. For CSIRO these impact pathways are many and varied, including advice and report submissions to Government agencies to be used as policy inputs in renewable energy areas.

CSIRO contributes to the development of Australia's science and engineering skill base by providing opportunities for collaboration with universities through CSIRO supported university supervised PhDs and by CSIRO training opportunities for post graduate students. In 2012-13, energy research encompassed 43 PhDs and 16 Postdoctoral Researchers.

Performance

CSIRO measures its science against two dimensions. The first is science excellence and its contributions to academia and advancing science frontiers. The second is the benefits delivered to intended users and ultimately the impacts to society, the environment and the economy. CSIRO's annual report outlines such impacts (see www.csiro.au/Portals/About-CSIRO/How-we-work/Budget--Performance/Annual-Report.aspx).

CSIRO conducts regular reviews of its research activities by expert panels of external stakeholders from academia and industry, from both Australia and overseas, to assess Flagships and Divisions against these two dimensions on a four yearly basis. The Energy Transformed Flagship was reviewed in 2012 and the external panel assessed it as "best practice" with regard to its people, external relationships and innovative collaborations, dimensions of which are built upon the science reputation of CSIRO.

The external panel rated each theme of the Flagship's research as Strong on the science dimension (this is the second

[23] *The following section has been provided by CSIRO and makes use of data from Thomson Reuters InCites*

highest rating and reflects CSIRO as ”Able to set and sustain new scientific/technical directions within the international research community”) and Strong on the Impact dimension (this is the second highest rating and reflects that “The research results are such that they enable commercial, environmental, community or policy development that distinguishes user organisations from peers or competitors”).

Science Output and Excellence

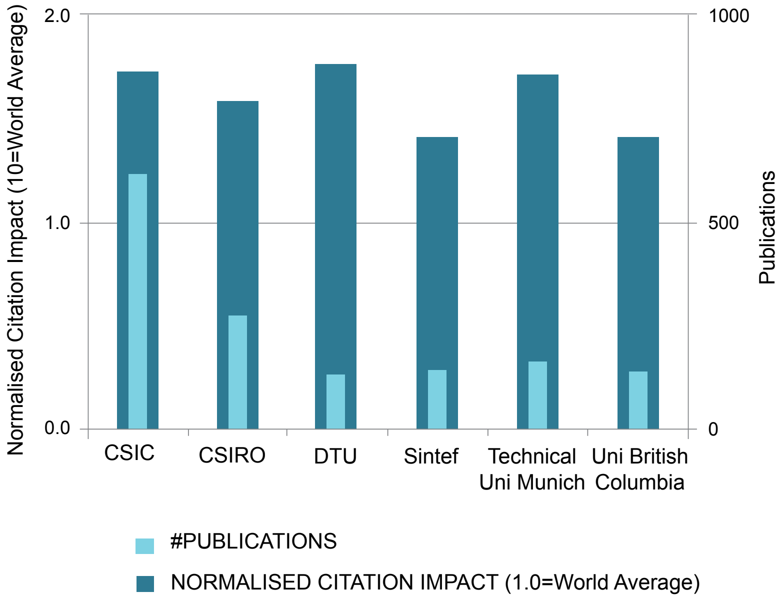
CSIRO produced 0.3% of global publications in the subject Energy and Fuels (which includes both renewable and non-renewable research) in the period 2008-2012 (Figure 23). It is the second largest contributor to Australia’s output in this subject, producing 13% of the country’s publications in the same period. Moreover, the rate of growth in such output has increased by 180% since 2008 when 31 journal publications were published compared to 87 publications in 2012. It is possible to express the relative specialisation on energy research for an institution, by comparing the proportion of that institution’s publications appearing in the subject with the global background proportion. This measure of specialisation is given relative to a global average of 1.0. CSIRO has the second highest level of specialisation in energy research of the major contributors to Australia’s publications in this subject. The organisation therefore not only contributes a substantial volume of output, but has a high degree of focus on the subject.

As in the rest of this Discussion Paper, the excellence of CSIRO’s research in energy is primarily measured using citation analysis. The calculation of the Normalised Citation Impact depicted in Figure 24 is similar to the Relative Citation Impact elsewhere in the Discussion Paper, except that citation baselines are also broken down by document type, as well as subject and year. The subject scheme used is from Web of Science, rather than the four-digit FoR codes (CSIRO does not analyse its research publications by FoR code) and the citation data are drawn from Web of Science rather than Scopus. For these reasons, the two citation analyses are not directly comparable.

It is also worth noting that, in keeping with CSIRO’s mission to deliver profound impact through excellent science, much of the organisation’s energy research is applied rather than basic. This has two effects: first, all other things being equal, applied research tends to receive fewer citations than basic research in technical fields; and second, natural peers for comparison are likely to be found elsewhere than Australia. CSIC[24], Sintef, DTU[25], the Technical University of Munich and the University of British Colombia were among the institutions identified as either producing similar research or having a similar mission to CSIRO in this area.

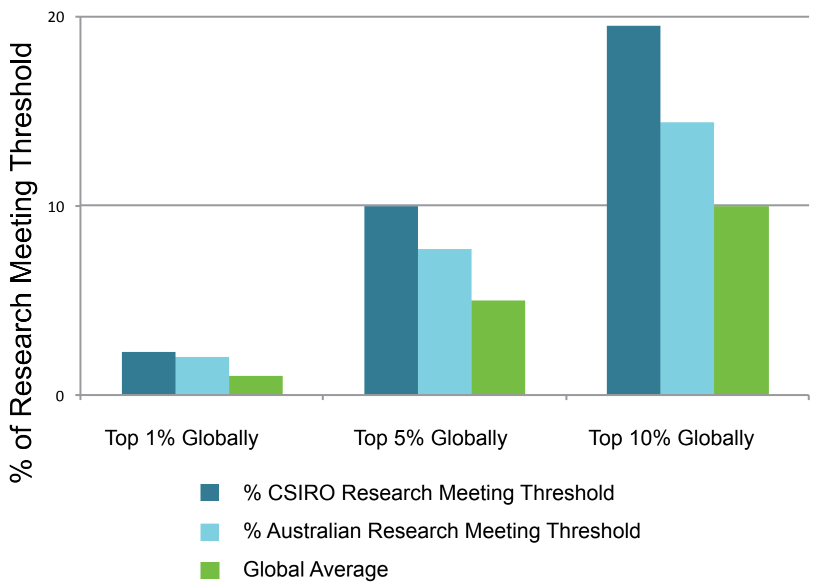
[24] *Consejo Superior de Investigaciones Científicas*
[25] *Technical University of Denmark*

Figure 23 CSIRO output and citation impact in Energy and Fuels, 2008-2012



Overall, CSIRO's research in Energy and Fuels is 59% more cited than the global average, accounting for publication age, type and subject mix. This is in line with the result for Australia, calculated using offline citation records rather than Web of Science online data.

Figure 24 CSIRO, Australian and global citation percentiles in Energy and Fuels, 2008-2012



Another bibliometric perspective of the quality of CSIRO's research comes from citation percentiles (Figure 24). Here, each article in each subject and in each year receives a percentile rank by its citation count. Counting the proportion of an institution's research appearing in the top 1%, 5% and 10% shows how far ahead of the curve an institution's publications are. CSIRO produces almost twice as much research in the top 1%, 5% and 10% as the global average, indicating that its research is of exceptional interest to the global research community.

A third perspective on CSIRO's research looks not at its quality but at a proxy measure for the esteem in which it is held (Figure 25). For reasons well documented and widely known, Impact Factors (or any journal metric) should not be used to evaluate the quality of an individual piece of research; however, the frequent appearance of researchers from an institution in the author lists of articles in top journals does improve the reputation and esteem of that institution's research.

Figure 25 CSIRO and global Impact Factor quartiles in Energy and Fuels, 2008-2012

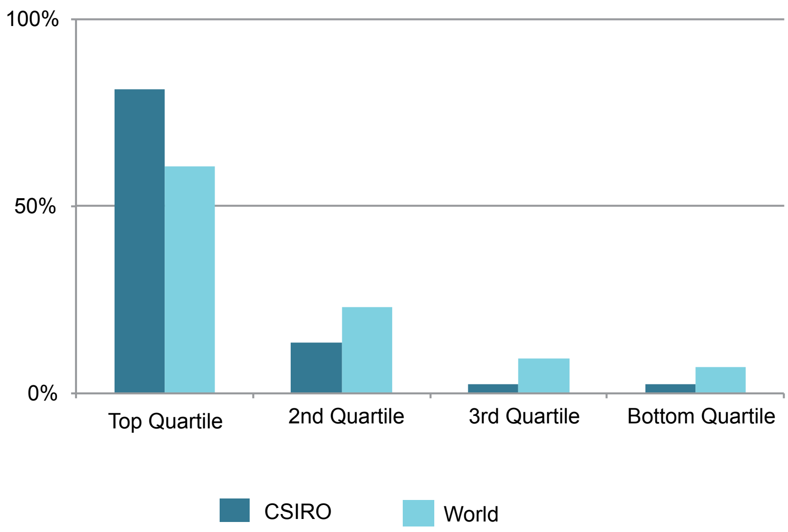


Figure 25 shows that CSIRO publishes substantially more of its research in the top ranked journals than the global average; while not necessarily an indicator of the quality of this research, it is representative of its reputation.

Necessary to CSIRO's research in renewable energy is the interdisciplinary nature of the capability involved in its research activity. CSIRO's research publication outputs relevant to energy are generated across 10 divisions. While 47% is generated through CSIRO's Energy Technology Division, the balance of outputs are generated from nine other CSIRO Divisions including capability involved in earth sciences, material and resource engineering, and ecosystems. A total of 9.4% of publications from 2008-2012 involved interdisciplinary collaboration between multiple CSIRO Divisions.

Impact

The focus on applied research delivering impact is clear from CSIRO's patent portfolio. Although the World Intellectual Property Organization (WIPO) does not have a code dedicated to renewable energy, 5.7% of CSIRO's patents are in the technology field of Electrical Machinery, Apparatus and Energy, compared to 2.5% for Australia.

CSIRO's real-world impact in energy research is delivered through three themes:

- **Carbon futures,** with the objective to deploy an integrated energy, water, food and carbon assessment service to help Australia identify the least cost and risk transition pathways to a prosperous and secure low carbon future.
- **Sustainable stationary energy and transport**, with the objective to drive the cost-effective take-up of renewable electricity and transport fuels in Australia to 2020 and beyond and maximise the long-term renewables uptake to 2050.
- **Local energy systems**, with the objective to reduce greenhouse gas emissions by driving the uptake of distributed energy solutions, demand reduction and energy efficiency measures to 2020.

Overall, the goal of the Flagship is to develop, demonstrate and ensure deployment by 2020 of integrated low-carbon pathways for Australia and alternative stationary and transport energy solutions that realise a reduction of Australia's carbon dioxide equivalent emissions greater than 20 million tonnes per annum by 2030, and greater than 50 million tonnes per annum by 2050.

The Energy Transformed Flagship has invested in the largest solar thermal power research capability in the southern hemisphere and is currently delivering more than $150 million worth of solar thermal projects for industry and government. Solar thermal technology uses mirrors or lenses to concentrate sunlight. This sunlight is converted into heat to drive a turbine connected to an electrical power generator or for integration into industrial processes such as fuel production. The resulting solar power has low-to-zero carbon emissions and the research team aims to make the price competitive with fossil fuels in the future.

In December 2012, a joint collaboration with ARENA was announced, with the Flagship leading the $87 million Australian Solar Thermal Research Initiative (ASTRI). The collaboration includes eight national and international research partners and is the largest Australian solar thermal, or concentrating solar thermal power collaboration and investment to date. ASTRI aims to reduce the cost of solar power by half (down to 12 cents a kilowatt-hour) and, by developing storage, allow solar power to supply the grid with electricity on demand.

During the reporting year, the Flagship collaborated with General Electric to further develop the Flagship's SolarGas™ technology and its transition to commercialisation. SolarGas™ combines natural gas with solar power to create a fuel that is 25 per cent more powerful than natural gas. This fuel can be burnt to produce electricity with lower carbon emissions than natural gas or can be turned into a transport fuel.

In the first half of 2013, the Flagship commissioned the world's first solar-powered high temperature steam receiver, which may assist coal-fired power stations transition to an increasing share of solar energy. Coal-fired power stations across Australia currently use steam to power turbines to generate electricity and the introduction of a solar receiver could one day be a retrofit option that will use a free energy source (the sun), reduce carbon emissions and decrease the reliance on fossil fuels.

Collaboration

CSIRO also places high importance on collaboration. 39% of CSIRO's Energy and Fuels publications from 2008-2012 were produced with domestic collaboration, most frequently with (in descending order) Monash University, UNSW, the University of Newcastle, the University of Western Australia, the University of Melbourne, the University of Wollongong and Curtin University of Technology.

Examples of the collaborations with universities include:

- Flagship Collaboration Fund Clusters in Hydrogen Pathways, Biofuels, Intelligent Grid and Future Grid. Each cluster involves 4 to six national and international universities undertaking research in an area aligned to CSIRO's Flagship Strategic Plan, with a focus on building cross-organisational linkages.
- ASTRI is an 8-year collaboration led by CSIRO with six Australian universities and US research laboratories, devoted to the reduction in future cost of concentrating solar thermal technologies.

It is possible to use research publication network metrics to evaluate the importance of an institution to a research ecosystem within a subject. Below, network metrics for the most important Australian 'nodes' are calculated for the Energy and Fuels subject, derived from a network based on the frequency of publication collaboration. Eigenvector Centrality uses a methodology similar to Google's PageRank to establish how important a node is, while Betweenness Centrality looks at how frequently a node is on the shortest path between two others. The results in Table 5 show that CSIRO is the most central node in the Australian network.

Table 5 Australian publication collaboration network metrics in Energy and Fuels, 2008-2012

LABEL	EIGENVECTOR CENTRALITY	BETWEENNESS CENTRALITY
CSIRO	1.000	8,955
University of Queensland	0.820	3,587
UNSW	0.533	4,146
University of Western Australia	0.471	1,052
Curtin University of Technology	0.462	2,606
Monash University	0.423	4,098
Griffith University	0.418	460

30% of CSIRO's energy publications involved collaboration with partners from overseas. These partners generally came from countries with a high frequency of collaboration with CSIRO as an organisation – specifically the USA, China, Germany, France, the United Kingdom and Canada.

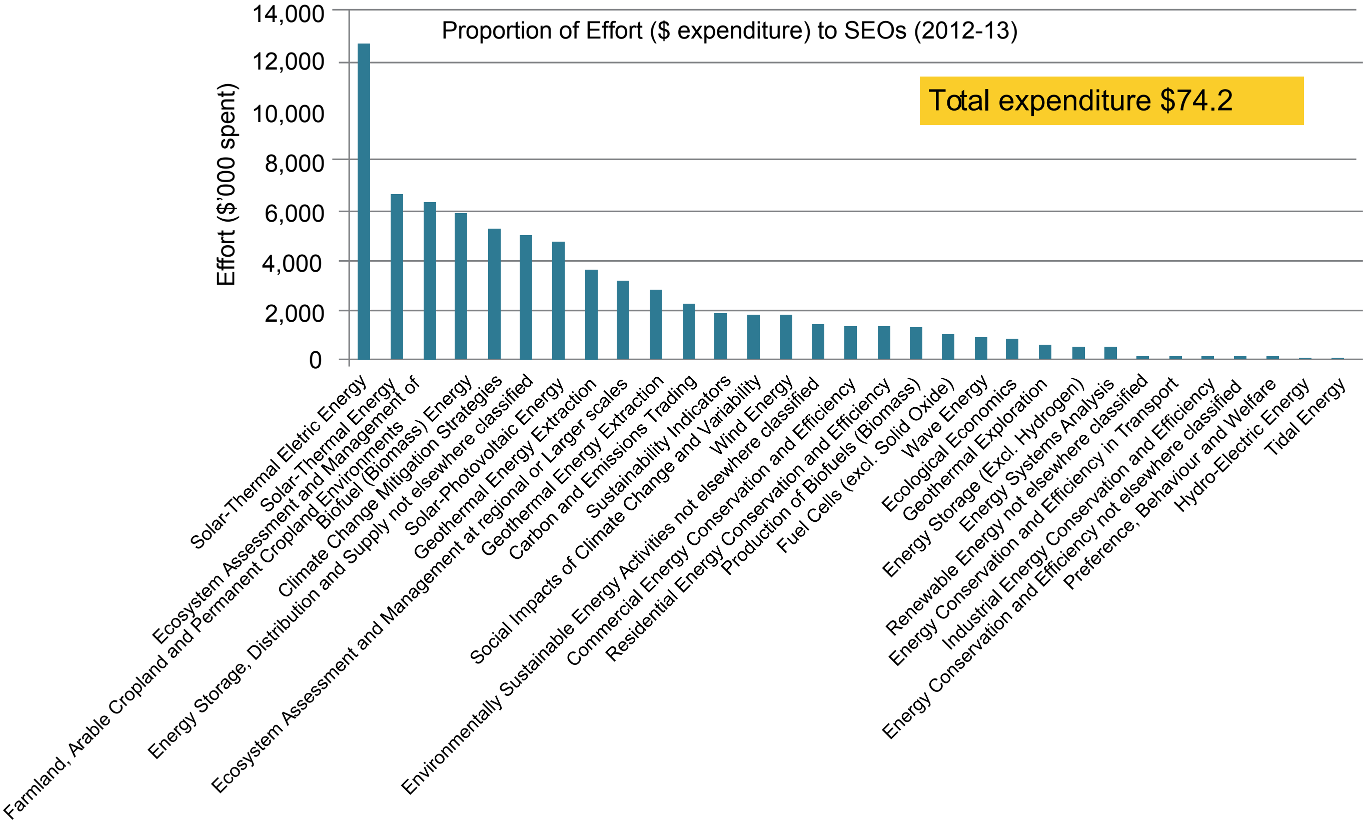
Eight per cent of CSIRO's energy publications were produced in collaboration with industry. Notable collaborators include Sasol Technology, China National Offshore Oil Corp, Furukawa Battery Co Ltd, Philipp Schramek Energy Consulting, PetroChina, the European Advanced Lead Acid Battery Consortium, SciWest Consulting, Konarka Technology GmbH, Provector Ltd, BHP Billiton, Chevron Energy and Origin.

Areas of focus

A publication keyword analysis conducted in 2012 identified a number of broad themes within Energy and Fuels globally and was used to show CSIRO's science excellence focus. This analysis was based on the visual identification of calculated clusters, and so is a broad measure which could not be used to evaluate the citation impact of clusters. However, the themes of Oil, Coal, Gas, Diesel, Solar, Water, Wind, Hydrogen, CO2, Batteries, Catalysis, Residue, Policy and Ethanol were established; of these, CSIRO was found to be heavily active in all except Diesel, Wind and Ethanol.

A further indicator of future publications in renewable energy is the relative investment in renewable area domains by SEO code, which shows CSIRO's focus in impact. As this is based in technology rather than publications, results can be quite different from those presented above. Figure 26 shows CSIRO's breakdown of expenditure by Socio-economic objective code (SEO) for 2012-13. The Figure demonstrates the high level of investment in solar thermal technologies, biofuels related research and other renewables, with small levels of research related to ocean energy systems. This is quite a different profile from Figure 5 in Section 2, where the analysis of publications from all research areas shows the top five ranked areas to be related to different families of photovoltaic cells.

Figure 26 CSIRO research effort related to renewable energy SEO codes



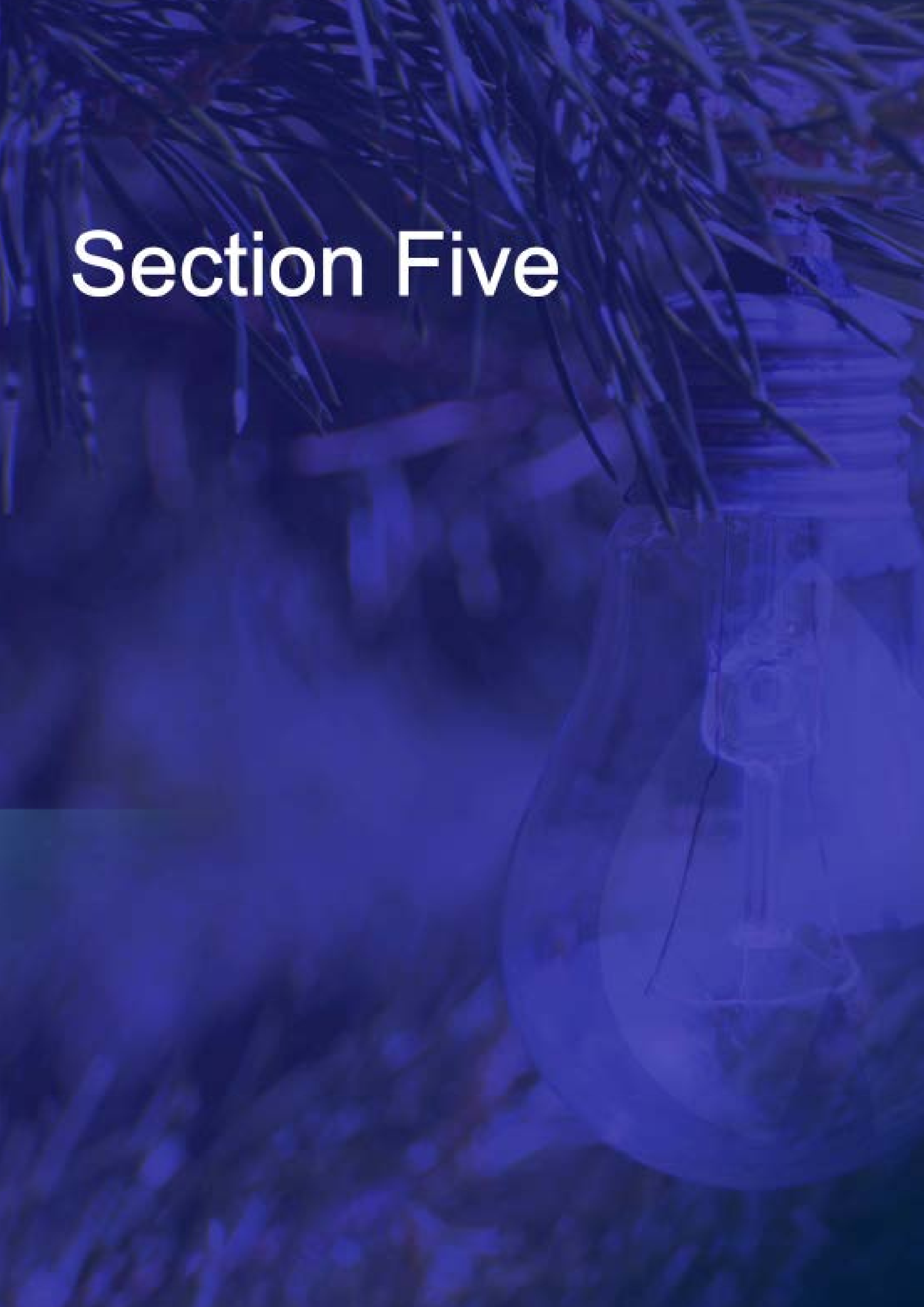
A further point of differentiation from the research conducted by many universities is the scale of CSIRO pilot scale research conducted in the renewable energy domain. Figure 27 shows the solar 1.2MWth thermal research facility and Renewable Energy Integration Facility at CSIRO's Newcastle Energy Centre. For industry, demonstration of research outcomes at pilot scale is a key step in their engagement with research and the adoption of research into new industrial processes.

Summary

In keeping with its unique position in Australia's research ecosystem, CSIRO's research into energy and fuels is both distinctive and of a high quality. The organisation is a primary producer of this country's energy research, delivering substantial academic and real-world impact in the area. Broad areas of renewable energy research include solar technology, energy storage and management, economic modelling, biofuels and geothermal energy. Working more closely with industry and more active in the sphere of patent activity, CSIRO is nonetheless the most influential node in the nation's publication network for energy and fuels.

Figure 27 Large scale pilot research facilities for applied research – (left) solar field consisting of 450 heliostats and central tower, (right) renewable energy electrical network

Section Five



Classifying RETechs Research

One of the key objectives of this Discussion Paper is to provide advice to ARENA about areas of RETechs research which are being conducted in Australia. As discussed in Section One, there are limitations on the usefulness of FoR codes as a descriptor for RETechs research: RETechs are by their very nature multi-disciplinary, and cross-over multiple FoRs. For this reason, identifying them initially required the use of keyword matching. However, this too has limitations in terms of classifying RETechs research: a term such as 'solar cell', for example, is itself a broad catch-all for a number of underlying technologies, and from a range of disciplinary perspectives. This top-down approach is useful for identifying the broad areas of research, but will not provide a fine grained map of the discrete RETechs research being undertaken.

The following analysis makes use of bottom-up, exploratory techniques to classify the RETechs articles by the similarity of the terms they use. This provides a detailed mapping wherein the RETechs research concepts can emerge from the data. These form the basis of the identified RETechs research areas.

Two techniques are used (see Appendix G: Correspondence Analysis and Hierarchical Clustering): Correspondence Analysis (CA) is used to first create a Document Term Matrix (DTM) and then reduce this to a low-dimensional space. In effect, this places all the Terms contained within the RETechs articles (the Documents) in a two-dimensional space where the distance between them is determined by their co-appearance in the Documents.

Hierarchical Clustering (HC) is then used to group the documents together based around the dimensions of the CA: the documents are grouped together based on which Terms are used in them.

This approach allows that the various concepts that are being researched in the RETechs articles can be grouped together at a much more fine-grained level than is possible with FoR codes or preconceived keywords.

The Corpus of Australian Research

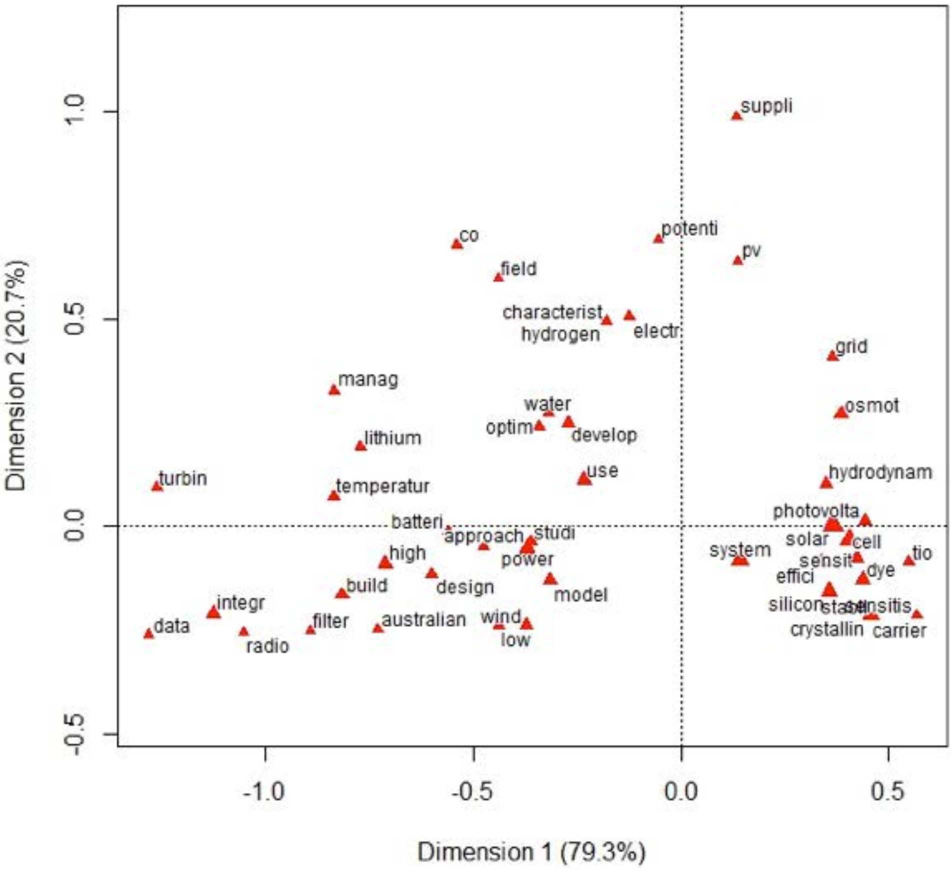
The corpus of Australian research for the following analysis includes articles from the university sector and CSIRO. This corpus contains 1337 Documents[26] containing 3114 Terms. Figure 28 includes all Terms that occurred more than 0.25% (32 times in the corpus). A small number of Terms occur greater than 1%: 'solar' (2.56%), 'cell' (2.5%), 'power' (1.94%), 'system' (1.73%) and 'silicon' (1.11%).

Correspondence Analysis

Figure 28 displays the two-dimensional chart of results of the CA visualising only those words that occurred more than 0.25%.

[26]*See Appendix G: Correspondence Analysis and Hierarchical Clustering for further details on outliers and 'false-positives'.*

Figure 28 Correspondence Analysis of Common Terms



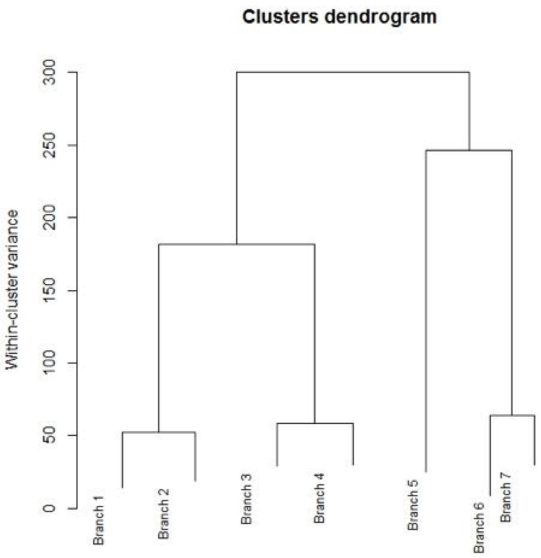
There are a number of distinct areas to the chart, and in even this limited set (around 50 of 3114 Terms) clear technologies are obvious. For example, the lower right-hand side includes all the Terms related to ‘solar’ including the whole and part search terms ‘crystallin’, ‘silicon’, ‘photovolta’, ‘cell’, ‘dye’, and ‘sensit’.

Each Term in the analysis is plotted along these two dimensions, which assists in identifying the strength of the relationships between them.

Hierarchical Clustering

The two-dimensional information from the CA above is used as the basis of the HC that follows. Seven Clusters were retained in the HC analysis (Figure 29).

Figure 29 Dendrogram of clusters



The decision to retain a Cluster was based on whether there were 50 or more outputs allocated in it. Again, this is broadly consistent with the ERA definition of research activity. As the advice of this Discussion Paper is to be used within the strategic development of ARENA's funding programs, a low-volume threshold is important – identifying areas smaller than 50 outputs across the 6 year reference period would potentially lead to unreliable outcomes.

Table 6 provides the number[27] and percentage of the documents that are included in each Cluster.

Table 6 RETechs outputs by Cluster

Cluster	Number	%
1. Solar Cell Technologies: A	178	13.4
2. Solar Cell Technologies: B	226	17.1
3. Wind and Converters	197	14.9
4. Hydrodynamics, inverters and hybrids	254	19.2
5. Building	179	13.5
6. Batteries and Geothermal	75	5.7
7. Hydrogen and Biofuel	216	16.3

To classify these Clusters, during the HC analysis, each article is clustered based on its linguistic similarities with the other documents in the Cluster. Each Cluster, then, is characterised by a number of prevalent terms which connect the papers with each other.

[27] *The total number excludes some outliers (e.g. 'false-positives' from the keyword matching). See Appendix G: Correspondence Analysis and Hierarchical Clustering for details.*

Figure 30 displays the Clusters as they appear mapped back into the results of the CA.

Figure 30 Correspondence analysis with clusters

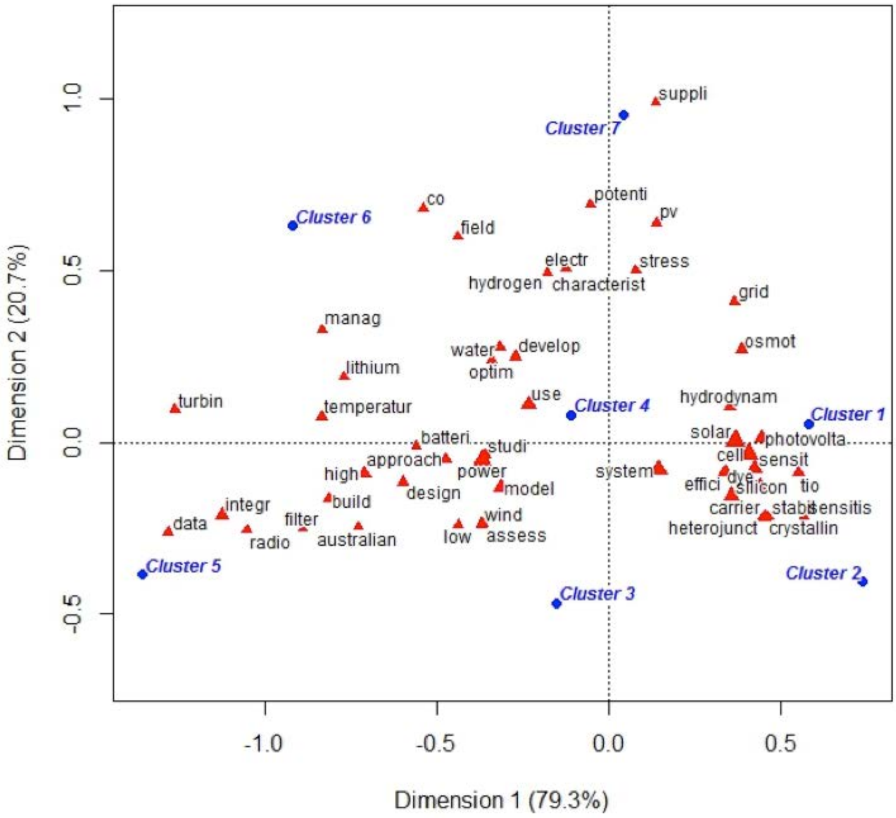


Table 7 displays the top five[28] words that characterise each of the Clusters.

Table 7 Top five most contributing terms by Cluster

Cluster	1	2	3	4	5	6	7
5 most contributing terms	cell	cell	power	energi	build	lithium	osmot
	solar	dye	system	diesel	integr	co	renew
	quantum	sensit	control	hydrodynam	data	batteri	stress
	dot	solar	stabil	generat	radio	reservoir	suppli
	photovolta	silicon	wind	particl	manag	temperatur	australia

[28] *Based on their t-values.*

Each of these Clusters can thus be seen to represent one or more[29] RETechs research areas in Australia. Table 8 provides a classification of the various Clusters and which RETechs research they include[30]:

Table 8 RETechs research by Cluster

Cluster name	Solar cell technologies: A	Solar cell technologies: B	Wind and converters	Hydrodynamics, inverters and hybrids	BuildingB	atteries and geothermal	Hydrogen and Biofuel
	Silicon	Dye sensitized solar cells	Hybrid wind power	Electric hybrid vehicles	Sustainable buildings	Lithium ion batteries	Hydrogen storage
	Crystalline silicon	Organic dye	Hybrid systems	Photovoltaic power generation	Building materials	Graphenenano sheets	Solar-hydrogen systems
	Quantum dots	Ti02 cells	Wind-diesel hybrid power	Hydrodynamics		Geothermal power plants	Osmotic energy
	Polymer solar cells	Hetero-junction cells	Voltage control	Smoothed particle hydrodynamics		Geothermal reservoirs	Gasification
	Photovoltaic cells	Polycrystalline silicon	Hybrid converter	Thermoelectric generators			Bio-fuels
	SI Quantum dots	Thin films	Power systems	Magnet generators			Bio-mass
	Luminescence imaging	Tandem solar cells		Inverters			Activated sludge
	Hot carrier solar cells	Nano crystalline					
	Photo electrochemical Cells						
	Super lattice systems						

[29]A number of Clusters include two or more distinct RETechs. For example, Cluster 6 includes Batteries and Geothermal Energy. The Clustering algorithm grouped these together based upon a shared reference to 'temperature' and thus they should be considered as sub-Clusters.

[30]The classification is based on the technologies and research areas that are present in the articles with the Cluster, and with reference to the Terms that contribute to each Cluster – for example, Cluster 1 included significant contribution from the Term 'Photovolta'. This Term was mainly used by Documents in Cluster 1 with reference to 'Photovoltaic cells'.

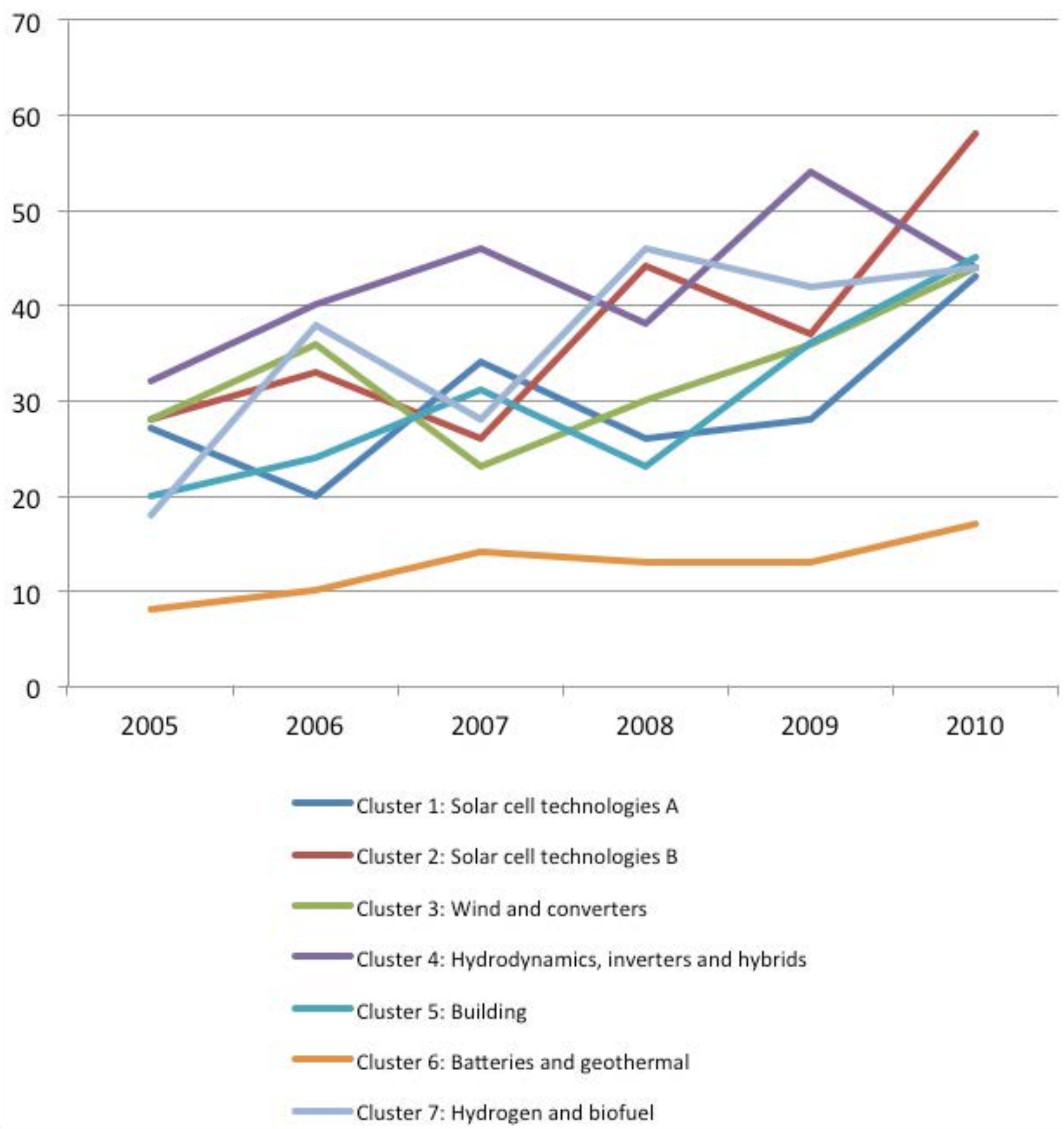
In addition to the above table, it should be noted that ‘turbines’ and ‘blades’ appeared throughout many of the groups, including Cluster 3, Cluster 4, Cluster 5 and Cluster 6. This therefore probably deserves to be included as an eighth, implied Cluster in this analysis.

Of all of the Clusters, the two including solar cells are more demarcated than the others – that is, they present clear RETechs that are easily distinguished. This is clear from the neat groupings of terms that have been included in Table 8. Cluster 1 is characterised as research into quantum dot and crystalline silicon cells, while Cluster 2 is characterised as research into dye-sensitized solar cells. In addition to being the neatest, Clusters 1 and 2 account together for approximately 30.5% of the RETechs research. Clusters 1-2 also included an amount of work in modelling methods around solar energy.

Cluster 3 is a relatively neat grouping of work into wind power, with a discernible focus on hybrid wind power (often wind-diesel). Cluster 4, which was the largest Cluster, is comprised of two sub-clusters, one in hydrodynamics (especially smoothed particle hydrodynamics), and the other in hybrid technologies (other than wind). Cluster 5 presents a relatively small focus on sustainable and energy-efficient building design. Cluster 6, in addition to being the smallest of the group, is also characterised by two distinct sub-clusters, lithium ion batteries and geothermal power. This latter is the smaller of the two sub-groups. Cluster 7, while still quite large at 16.3% of the RETechs research identified in the keyword matching, is characterised by a number of potential false-positive results, with a large inclusion of work on ‘plant stress’ and ‘osmotic adjustment’ in plants. However, this is also one of the Clusters that more prominently features work on biomass and bio-fuels, and so this work may or may not be considered appropriately included.

The trend data for each Cluster is presented in Figure 31 for the reference period.

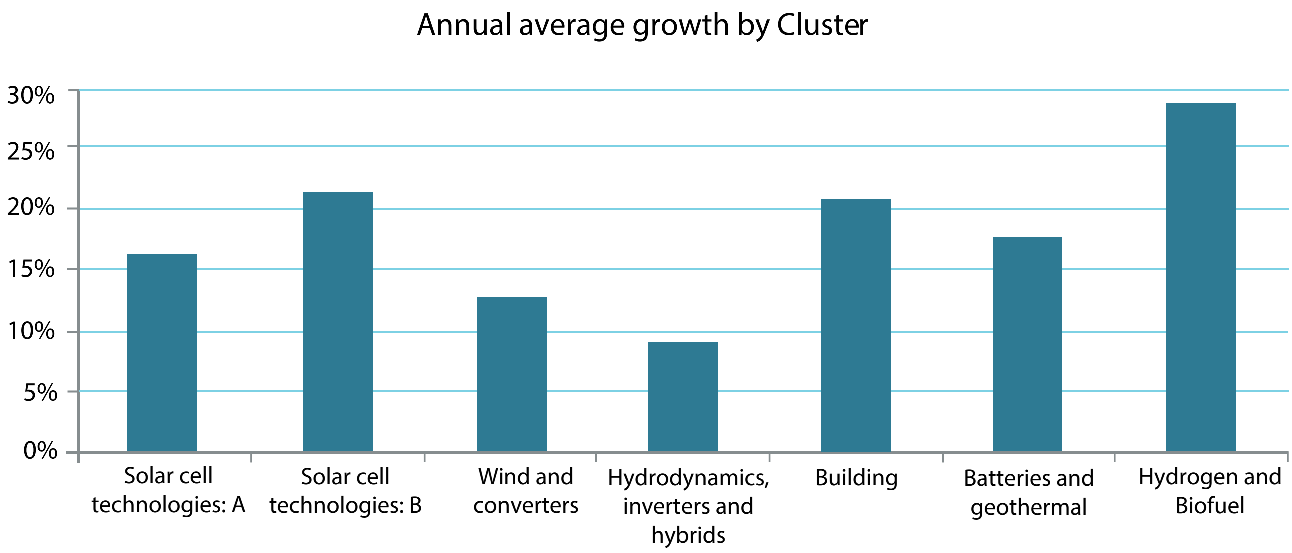
Figure 31 RETechs publications by Cluster for the reference period



All of the Clusters are growing across the reference period which confirms the observation from Section Two that RETechs research is generally an emerging area in Australian research. To account for the peaks and troughs in the growth and the relatively low number of papers, the growth is provided as an average annual growth percentage in Figure 32.[31]

By this measure all Clusters are indeed growing, on average across the period at between 9% (Cluster 4) and 29% (Cluster 7). Again, this confirms the earlier observations about RETechs research as an emerging area, but also identifies a large degree of variation within RETechs research.

Figure 32 Annual average growth of RETechs outputs by Cluster

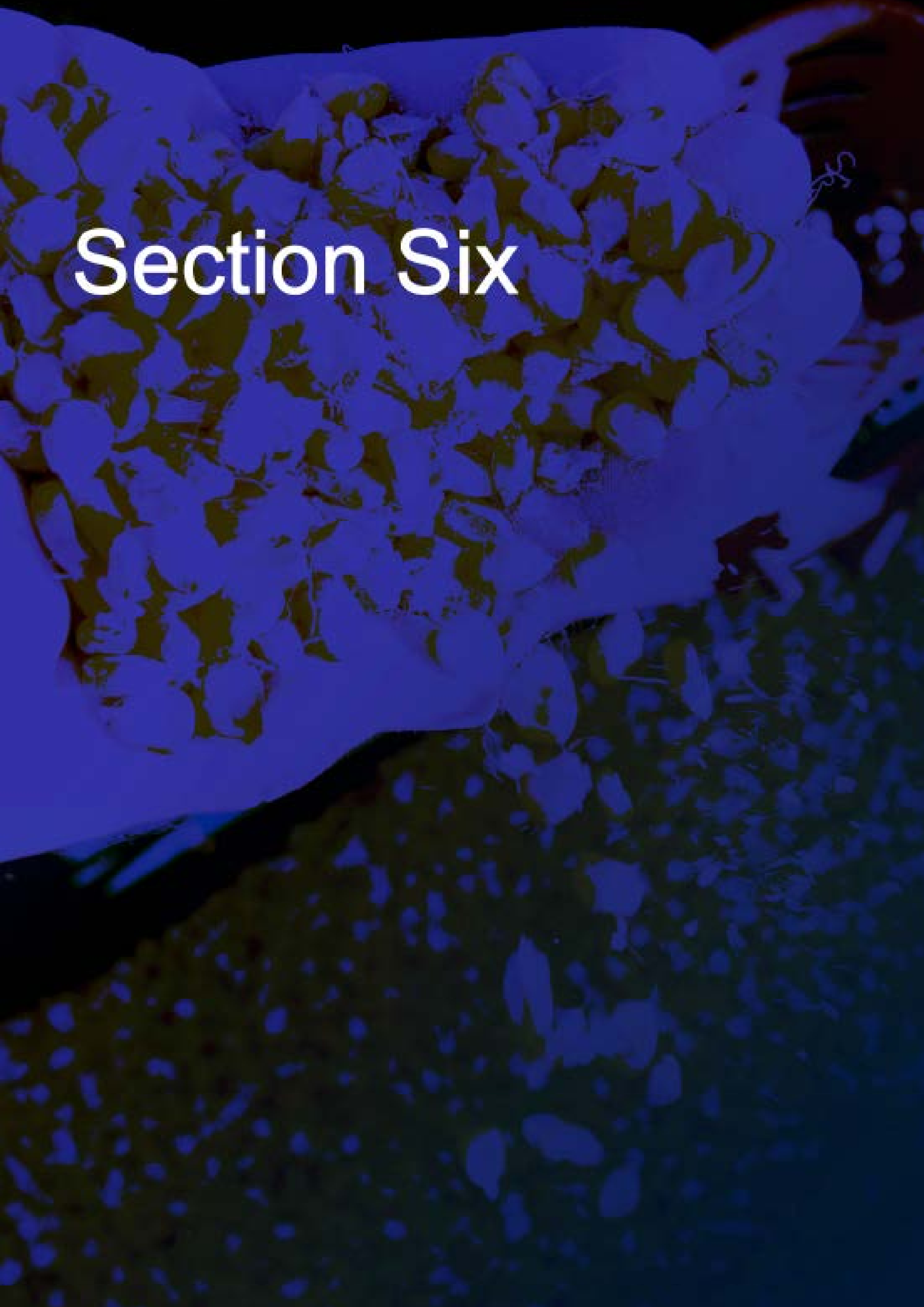


Summary

From the above analysis, it is apparent that there are a number of discrete RETechs being researched in Australia, to a greater or lesser extent. With reference to ARENA's definitions of renewable energy, this Discussion Paper has identified work under Geothermal Power, Hybrid Technologies, Ocean Power, Solar Power and Wind Power. Of all of these areas, technologies around Solar Power are clearly an area of focus within Australia's RETechs research effort.

[31]*Annual average growth rate is the arithmetic mean of arithmetic mean of the growth rate over each annual period i.e. the average growth from 2005-2006, 2006-2007, 2007-2008 etc. The annual average growth is preferred in this case as it provides a mid-point between the compound annual growth rate (CAGR) and the two-period growth rate, both of which have been used to express the growth of disciplines elsewhere (see for example ERA 2012 National Report). For example, for Cluster 4 the CAGR is 7% and the two-period rate is 15%.*

Section Six



Conclusions

This Discussion Paper has found that between 2005-2010 around 1-3% of university and CSIRO research articles were related to RETechs (for a number of reasons this is likely under-reporting the total R&D effort). The Paper has found in excess of 1,000 journal articles that were published by universities and CSIRO into RETechs. For university-based work, the majority were located within the broad discipline Division of Engineering, and primarily within the discipline Groups of Materials Engineering, and Electrical and Electronic Engineering. There was also a significant amount of work produced in the discipline Group of Condensed Matter Physics.

The key discipline Groups underpinning RETechs research are considered to be high-performing within the ERA evaluation exercise, where the quality of university research in these disciplines was judged to be primarily at world standard or better. The evidence is that this quality is improving over time relative to world standards, with increased ERA ratings between the 2010 and 2012 rounds.

Significantly, the research articles within these disciplines specifically identified as RETechs research perform more highly than the underpinning research disciplines on key citation indicators such as the Relative Citation Index and RCI Class Distribution. These indicators demonstrate that in some instances RETechs research is performing on average three or more times the world average which identifies RETechs research as a pocket of national strength.

In terms of basic research activity, the numbers of articles are comparatively small within the underpinning disciplines, representing, for example, approximately 2% of the research publications in Materials Engineering. However, the aggregate total output is significant and compares with the total output for some disciplines, including disciplines in Engineering. The level of RETechs research output over the six years of the study period is relatively constant with the exception of work in Electrical and Electronic Engineering, which has steadily increased and is approximately double the level of output from beginning to the end of the study period. Both the contribution of universities and CSIRO are increasing across the period, with CSIRO RETechs research growing an annual average of 23% between 2005 and 2010.

The Discussion Paper provides a measure of specialisation for the disciplines that underpin RETechs research. The Specialisation Index (SI) is an indicator of research intensity relative to the world, demonstrating Australia's degree of research focus in a particular discipline. The evidence in the Discussion Paper suggests that Australia is less specialised than the world average in the underpinning disciplines. The indication that these discipline Groups are nonetheless performing world standard and above research, with a pocket of very high-performing RETechs research potentially supports the case for further investment in RETechs research.

The Discussion Paper provides a 'conceptual map' of the R&D effort into RETechs, to assist ARENA in prioritising their theme-based funding rounds: for example, which are the particular RETechs that are being researched, and to what degree of concentration this is occurring. The Discussion Paper finds that the R&D effort can be classified into a number of discrete Research Clusters around:

Solar cell technologies A

- Quantum dot/crystalline silicon solar cells
- Modelling for solar cells

Solar Cell Technologies B

- Dye sensitized solar cells
- Multijunction photovoltaic cells

Wind and converters

- Hybrid wind power (especially diesel-wind hybrid)
- Energy conversion
- Blades and turbines

Hydrodynamics, inverters and hybrids

- Smoothed particle hydrodynamics (ocean power)
- Energy inversion
- Blades and turbines

Building

- Sustainable building
- Blades and turbines

Batteries and Geothermal

- Lithium ion battery storage
- Blades and turbines

Hydrogen and Biofuel

- Solar-hydrogen systems
- Bio-mass
- Bio-fuels
- Blades and turbines

RETechs research in Australia is concentrated around this small set of research areas. These are very highly cited relative to the world average, and are underpinned by research disciplines that have been evaluated to be mostly at or above world standard.

Appendices

Appendix A: Request for Services

ARENA is looking to ensure its future R&D funds are maximised and in line with ARENA's key objectives. These objectives are to support R&D that:

- sees Australia at the leading edge of development in this technology sub-category; and
- requires Australian specific R&D in this technology sub-category due to Australian specific conditions.

ARENA is keen to use the OECD standard to define R&D projects. In essence, ARENA considers that R&D projects are characterised by their originality and the primary objective of the work is investigation, the outcome of which will be new knowledge and may lead to practical application, new improved materials, products, processes or services.

For the purposes of this study R&D does not include implementing innovations (including trial production and copying of prototypes), education and training of students, maintenance of national and international standards, feasibility studies, the costs associated with patent and licence work, and policy, marketing and market studies. Whereas, specialised scientific and technical information services, the design, construction and testing of prototypes (pilot plants where new data is evaluated) are included.

The essential components of this study are:

- TASK 1 – Detail and explain the research areas and universities (and other key research bodies) within scope and the standard or approach used.
- TASK 2 – Outline the methodology applied to evaluate these research areas.

Task 1

The ARC has used the Australian and New Zealand Standard Research Classification (ANZSRC) codes to break down renewable energy research areas, at a high level. ARENA has identified the groups within scope of this study are:

Field of Research

- 0913 – Mechanical Engineering

Socio-Economic Objective

- 8501 – Energy Exploration (specifically 850102)
- 8503 – Preparation and Production of Energy Sources (specifically 850309)
- 8505 – Renewable Energy
- 8506 – Energy Storage, Distribution and Supply

But has asked the ARC to validate this list, explore further as is appropriate and explain the final list with the outcomes of the study.

ARENA expects that the research areas are not evaluated at field level but rather with more granularity.

Example using the ANZSRC:
Level: Socio-Economic Objective
Division: 85 Energy
Group: 8505 Renewable Energy
Field: 850504 Solar-Photovoltaic Energy
Category: to be determined by the ARC
Sub-category: to be determined by the ARC

The universities and other research bodies evaluated by the study must be justified and reasonable.

Task 2

ARENA has asked the ARC to develop an objective methodology which will have the end result of highlighting priority research areas meeting ARENA's R&D objectives. The methodology is expected to be applied to the research areas and universities and research bodies identified in Task 1. The reference period for the evaluation is 5 years but may be variable for some of the indicators used in the ARC methodology.

The ARC is able to use a similar methodology for ARENA R&D Objective 1 as for Excellence in Research for Australia including volume and activity, publishing profile, applied measures such as patents, registered designs and so on. However, ARENA expects that the ARC will need to use an innovative approach to work out how to assess the research areas for R&D Objective 2.

Appendix B: Institutions Evaluated in ERA 2012

Australian Catholic University

Batchelor Institute of Indigenous Tertiary Education

Bond University

Central Queensland University

Charles Darwin University

Charles Sturt University

Curtin University of Technology

Deakin University

Edith Cowan University

Flinders University

Griffith University

James Cook University

La Trobe University

Macquarie University

Melbourne College of Divinity

Monash University

Murdoch University

Queensland University of Technology

RMIT University

Southern Cross University

Swinburne University of Technology

The Australian National University

The University of Adelaide

The University of Melbourne

The University of New England

The University of New South Wales

The University of Newcastle

The University of Notre Dame Australia

The University of Queensland

The University of Sydney

The University of the Sunshine Coast

The University of Western Australia

University of Ballarat

University of Canberra

University of South Australia

University of Southern Queensland

University of Tasmania (incorporating Australian Maritime College)

University of Technology, Sydney

University of Western Sydney

University of Wollongong

Victoria University

Appendix C: ARENA Keywords

The ARC has worked with ARENA to develop a list of keywords which cover the main aspects of RETechs research. The final list used in this Discussion Paper is as follows:

Advanced biofuels
Second generation biofuels
Thermochemical routes
Energy anaerobic digestion
Solar axis tracking
Balance of system
Battery storage
Biodiesel
Biogas
Bioheat
Biomass-to-liquids
BTL
Bio-oil
Blade fatigue
Blade optimisation
Blade shape
Wind Turbine blade
Photovoltaic
Solar PV
Solar Thermionic
Solar OPV
Organic Solar cell
Organic photovoltaics
Dye-sensitised solar cells
DSC
Silicon solar cells
Solar Concentrating PV
Solar CPV
Solar Inverter
Solar power system
Solar CSP
Solar CST
Solar Cell
Building Integrated Photovoltaic
BIPVs
BIPVT
Solar Capacitor
Central receiver tower Solar
Co-firing energy
Co-generation
crystalline silicon
Concentrating photovoltaic
Concentrating solar thermal
Dimethylether
DME
DNI
Downstream turbulence
Drop-in fuel biofuel
geothermal system
Enhanced geothermal system
Ethanol fuel
Feedstock
Flywheel
Gasification biomass
Geothermal characterisation
Geothermal energy
Geothermal flow rate
Geothermal reservoir
Green crude
Heliostats
high temperature ceramics
Hot dry rock
Hot Sedimentary Aquifer
Hydrodynamics
Hydroelectric
Hydroelectric turbine
In-stream flow
ionic liquid
Landfill gas
LIDAR
Lignocellulosic

Cellulosic
Fuel cellulosic
Energy cellulosic
Ethanol cellulosic
Linear Fresnel
lithium ion battery
Marine energy
Methanol fuel
Methanol biomass
Mini-wind turbine
Mirror field
Molten salts
Crystalline silicon
Crystalline silicon
Multi-junction cells
Municipal solid waste
MSW energy
Ocean current
wave energy converter
Ocean energy conversion devices
Ocean renewable energy
Ocean thermal
Oceanography
Organic photovoltaic devices
Oscillating water column
Osmotic
Parabolic dish
Parabolic trough
Pelletisation
Photonics
Plasmonics
Point absorber
Point actuator buoy
Power tower
Pyrolysis Biomass
Receiver tubes
Renewable diesel
diesel transesterification
Hydroprocessed esters fatty acids
hydroprocessed renewable
Reservoir permeability
Salinity device
tandem solar cells
Silicon wafer
Low head
Solar boost
Solar field
Solar thermal
Solar tower
SRF energy
Supercritical water
System Advisor Model (SAM)
Target formation
thermal storage
Solar Thin film
Tidal barrage
Tidal turbine
Torrefaction
Tri-generation energy
turbulence modelling
Wave device
Wave farm
Wave array
Geothermal well
Renewable energy reliability
fringe of grid renewable
off-grid renewable energy
stand alone renewable energy
remote renewable energy
hybrid renewable energy
mine renewable energy
remote area power supply
renewable energy integration
renewable energy penetration

Appendix D: Ranking Algorithm for Keyword Match

The keywords supplied by ARENA have been matched against research articles in the Scopus dataset to identify all relevant research articles. Each article is checked for whether it matches against one or more of the keywords and receives a score from 0-1000 to determine the significance of the match. The ranking algorithm is as follows:

Rank = Σ[Terms in Query] w (((k1 + 1) tf) / (K + tf)) * ((k3 + 1) qtf / (k3 + qtf)))

Where:

w is the Robertson-Sparck Jones weight.

In simplified form, w is defined as:

w = log10 (((r + 0.5) * (N – R + r + 0.5)) / ((R – r + 0.5) * (n – r + 0.5))

N is the number of indexed rows for the property being queried.

n is the number of rows containing the word.

K is (k1 * ((1 – b) + (b * dl / avdl))).

dl is the property length, in word occurrences.

avdl is the average length of the property being queried, in word occurrences.

k1, b, and k3 are the constants 1.2, 0.75, and 8.0, respectively.

tf is the frequency of the word in the queried property in a specific row.

qtf is the frequency of the term in the query.

(Microsoft)

Appendix E: Citation Benchmark Methodology

Citation data provider

The citation data used in this report was derived from Scopus custom dataset from Elsevier.

Calculating the benchmarks

World citations per paper (cpp) benchmarks

Scopus derived the ERA 2012 static citation dataset on 20 February 2012 for all publications for journals listed in the ERA journal list[32] published during the period 1 January 2005–31 December 2010.

The world benchmarks are derived using bibliometric data of all eligible articles published in the world. Only Scopus article types of journal article, conference publication and review article are included in the world benchmark calculations.

Scopus derives the benchmarks using the following calculation:

$$\text{World benchmark}_{\text{year(n) FoR(n)}} = \frac{\text{Sum of cites for all eligible articles in the world dataset}_{\text{year(n) FoR(n)}}}{\text{Total number of eligible articles in the world dataset}_{\text{year(n) FoR(n)}}}$$

Calculating the citation profiles

Relative Citation Impact (RCI)

An RCI is calculated for each article against the relevant Field of Research code and a year-specific benchmark. Once RCIs have been calculated for all articles, an average of a defined group's RCIs is then derived. The RCI against world benchmark is constructed individually for each defined group.

Steps for deriving RCI against World Benchmarks

The methodology for deriving the citations profile is:

1. Calculate 'RCI (world)' for each article in a defined group, where:

$$\text{RCI (World)} = \frac{\text{number of citations}_{\text{article x}}}{\text{World cpp}}$$

2. Apply the apportionment to individual article's RCI from Step 1, where

*Apportioned RCI (World) = RCI (World) * apportionment*

3. average the RCI derived in 2 where:

average RCI (world)= average of all 'Apportioned RCI (world)' for a UoE

Note that the denominator for 3 is the total apportioned count of indexed articles for the defined group.

[32] www.arc.gov.au/era/era_2012/archive/era_journal_list.htm

Appendix F: Specialisation Index

The Specialisation Index (SI) is an indicator of the research intensity in a given field of research. It compares the world share of articles with the share of articles in the Australian ERA data in that discipline. If Australia is specialised in a particular discipline, it places more emphasis on a particular discipline compared to other research areas. The SI is calculated as:

$$\textit{SI (specialisation index) DisciplineX} = \frac{\textit{Articles in DisciplineX Aust/Total articles in Aust}}{\textit{Articles in disciplineX World/Total articles in World}}$$

An index value above 0 means that a country is specialised relative to the world, whereas an index value below 0 means the reverse (Archambault, Lecomte and Picard-Aitken).

To present the SI graphically, the SI is transformed using the hyperbolic tangent of the natural logarithm (TANHln(x)). The resulting values are then evenly distributed between -1 and +1. This transformation has two advantages: it makes the distribution symmetrical on both side of the world average; and it gives more resolution in the area close to the origin where most of the values are located.

Appendix G: Correspondence Analysis and Hierarchical Clustering[33]

Importing and pre-processing

1. The Corpus of Documents is imported removing 'stopwords' and ' punctuation'
2. All words are converted to 'lowercase' and stemming is applied (using the Snowball C library). Stemming reduces inflectional forms of words to a common stem or root word, for example 'consign', 'consigned' and 'consignment' would all be represented by the common stem 'consign';
3. Terms missing from more than 98% of documents are removed to reduce insignificant Terms.

Correspondence Analysis

1. A 'Document Term Matrix' (DTM) is created. A DTM is a matrix in which each Term from the Corpus is a column, while each Document is a row. Where a Term appears in a Document it is represented with a '1', and where it is not a '0' as in the Table below:

	$Term_1$	$Term_2$	$Term_3$	$Term_n$
$Document_1$	0	11		Etc.
$Document_2$	1	0	0	Etc.
$Document_3$	1	11		Etc.
$Document_n$	Etc.	Etc.	Etc.	Etc.

2. Correspondence Analysis (CA) is performed. CA reduces the dimensionality of the DTM into a lower dimensionality. The total variance of the DTM is measured by inertia.[34]
3. Terms are only included where they meet all of the following criteria:
   a. Have a significance of at least 0.05
   b. Appear twice or more I the Corpus
   c. Do not appear in less than 1% of the documents.

[33] *Correspondence Analysis and Hierarchical Clustering are performed in R statistical package.*

[34] *Note that the CA R package restricts explanation eigenvalues of explained inertia to two dimensions where applicable Invalid source specified.*

Hierarchical Clustering

1. Hierarchical Clustering (HC) is performed retaining the dimensions of the CA analysis. A Complete-Linkage Clustering with Ward's minimum variance using a Chi-squared distance is used.
2. Documents are selected using a Euclidean distance weighted by the inverse term frequency and taking account of the different lengths of the documents.
3. HC begins by treating each document as a separate cluster, and then examines the distances between the clusters. The two clusters that have the shortest distance between them are then combined into a new cluster. This continues until all documents are presented into a single cluster.
4. The results of the keyword text-mining still include a number of 'false-positives' which may appear as outliers. To reduce the impact on the HC where outliers were identified as the basis of a resulting cluster, they have been removed from the data set. This improves the characteristics of the final clusters that are reported.
5. To remain broadly consistent with the ERA definition of research activity clusters were retained where they consist of more than 50 articles.

Appendix H: FoR codes identified with RETechs Publications

The four-digit code labels presented in this Appendix relate to the codes which are presented in Table 7 of the Discussion Paper. They are presented in numeric order in this Appendix, not in the order of the number of articles, or their relevance against the keywords.

Top five Disciplines which support RETechs research[35]

- 0204 Condensed Matter Physics
- 0904 Chemical Engineering
- 0906 Electrical and Electronic Engineering
- 0912 Materials Engineering
- 0913 Mechanical Engineering

Other disciplines linked with RETechs research outputs[36]

- 0102 Applied Mathematics
- 0201 Astronomical and Space Sciences
- 0205 Optical Physics
- 0303 Macromolecular and Materials Chemistry
- 0305 Organic Chemistry
- 0306 Physical Chemistry (including Structural)
- 0405 Oceanography
- 0502 Environmental Science and Management
- 0601 Biochemistry and Cell Biology
- 0605 Microbiology
- 0607 Plant Biology
- 0608 Zoology
- 0703 Crop and Pasture Production
- 0905 Civil Engineering
- 0907 Environmental Engineering
- 0908 Food Sciences
- 0910 Manufacturing Engineering
- 0914 Resources Engineering and Extractive Metallurgy
- 0915 Interdisciplinary Engineering
- 1007 Nanotechnology
- 1103 Clinical Sciences
- 1107 Immunology
- 1503 Business and Management
- 1605 Policy and Administration

[35] *These disciplines are described in more detail in the Discussion Paper*

[36] *The Australia and New Zealand Standard Research Classification (ANZSRC) provides a full description of these codes.*

Works Cited

Archambault, Éric, Nicolas Lecomte and Michelle Picard-Aitken. “Science-Metrix.” n.d. 10 October 2013 <http://www.science-metrix.com/pdf/SM_IC-OCA_Report_Consumer_Issues_Research_VF_rw.pdf>.

Australian Bureau of Statistics and Statistics New Zealand. Australian and New Zealand Standard Research Classification (ANZSRC) 2008. Canberra: Commonwealth of Australia, 2008.

Australian Renewable Energy Agency. About. n.d. 12 September 2013 <www.arena.gov.au/about-arena/>.

—. “General Funding Strategy 2013/14-2015/16.” 2013. 18 October 2013 <www.arena.gov.au/_documents/2013-14-GFS.pdf>.

—. “Investment Plan 2013/14-2015/16.” 2013. 18 October 2013 <www.arena.gov.au/_documents/2013-14-IP.pdf>.

Australian Research Council. “Excellence in Research for Australia (ERA) 2010 National Report.” n.d. Australian Research Council. 16 October 2013 <www.arc.gov.au/era/era_2012/outcomes_2012.htm>.

—. “Excellence in Research for Australia (ERA) 2012 National Report.” n.d. Australian Research Council. 16 October 2013 <www.arc.gov.au/era/era_2012/outcomes_2012.htm>.

CSIRO. Energy Transformed Flagship Overview. n.d. 12 10 2013 <www.csiro.au/org/Energy-Transformed-Flagship-Overview>.

CSIRO energy and renewables research: <www.csiro.au/Outcomes/Climate/Understanding/CSIRO-energy-and-renewables-research.aspx>

Ocean renewable energy <www.csiro.au/ocean-renewable-energy>

CSIRO Energy Flagship <www.csiro.au/Organisation-Structure/Flagships/Energy-Flagship/Energy-Flagship-Overview.aspx

CSIRO Energy Technology Division <www.csiro.au/Organisation-Structure/Divisions/Energy-Technology.aspx

CSIRO Energy Centre <www.csiro.au/en/Outcomes/Climate/Reducing-GHG/Newcastle.aspx

CSIRO Renewables and smart systems <www.csiro.au/Outcomes/Energy/Renewables-and-Smart-Systems.aspx

Microsoft. Understanding Ranking. n.d. 4 October 2013 <http://msdn.microsoft.com/en-us/library/ms142524%28v=sql.90%29.aspx>.

Green Energy - Solar Panels and Wind Turbines
©iStockphoto.com / 00Mate00

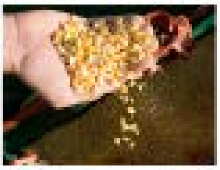
solar panels against a sunny sky
©iStockphoto.com /visdia

Wind Turbines
©iStockphoto.com / Bonerok

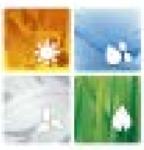
Spillway
©iStockphoto.com / IanChrisGraham

Recharging electric car
©iStockphoto.com / Firstsignal

Eco energy concept
©iStockphoto.com / kav777



Sifting through the corn
©iStockphoto.com / sbrogan



Alternative energy - Illustration
©iStockphoto.com / Laurelins