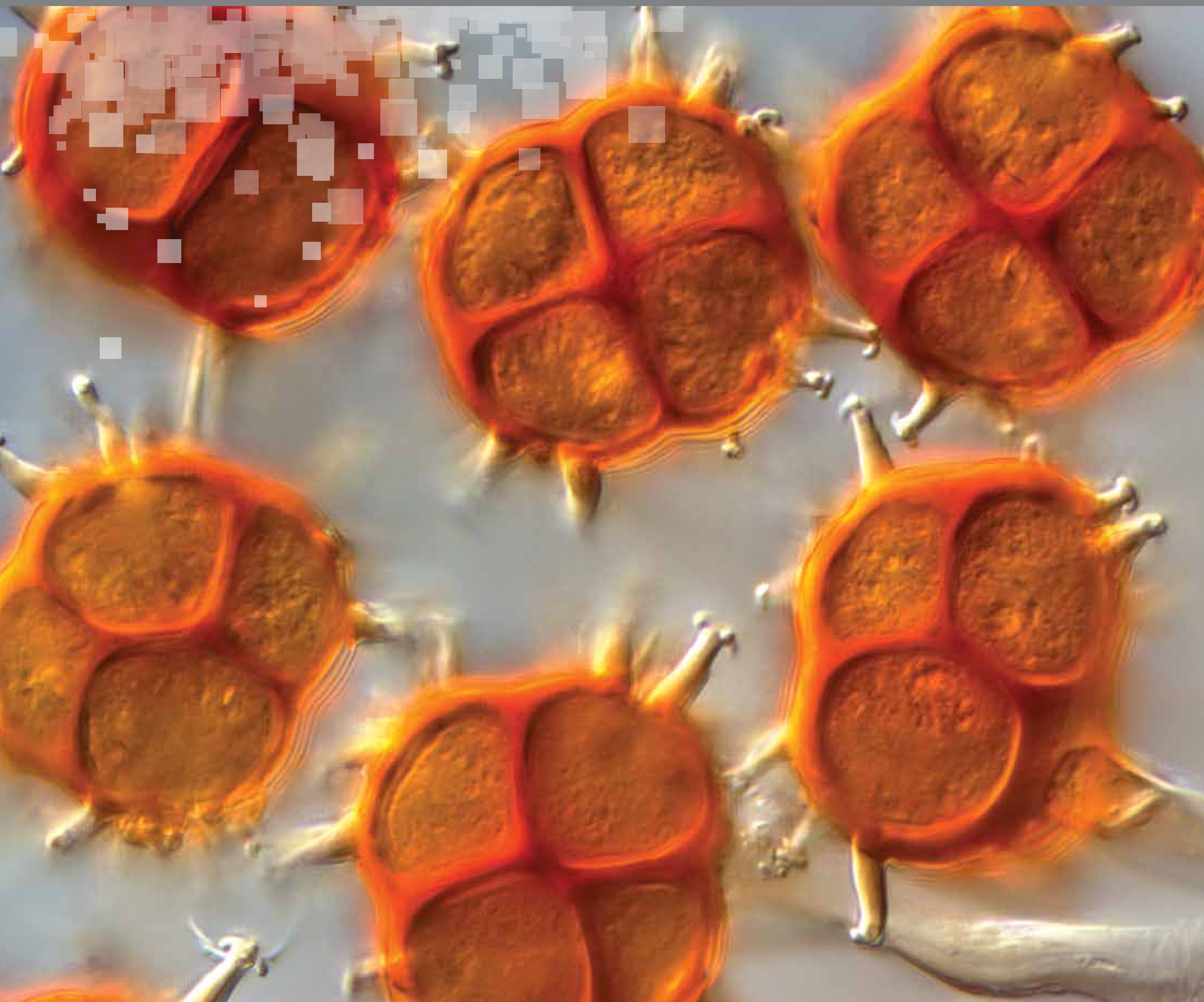
Australian Government

Department of Industry
Innovation, Science, Research
and Tertiary Education

2012 NATIONAL RESEARCH INVESTMENT PLAN



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Cover image - Teliospores of *Sphaerophragmium quadricellulare* on *Acacia pennata* (Courtesy of the Atlas of Living Australia, credit Dr Roger Shivas)

PRIME MINISTER'S FOREWORD

As the twelfth-largest economy internationally, Australia stands tall in the world. Our prosperity is no accident but has been built through careful long-term investment in skills, innovation and research.

But if Australia is to succeed in the Asian Century, we will need to deepen our strengths and capabilities. Only by doing this will we raise our productivity performance and be ready to take full advantage of the remarkable opportunities now unfolding in our region.

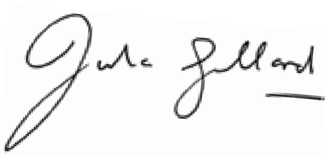
So we must be a nation where education and training provides individuals with opportunities to improve their lives, where the skills and inventiveness of Australians enable business and government to deliver better products and services, and where our open, flexible and innovative people can capture the benefits of the Asian Century.

This National Research Investment Plan provides a key roadmap to achieving these goals by ensuring that public investment in research and innovation is truly coordinated across the whole of government, and the discovery and use of new ideas makes the greatest possible contribution to the Government's broader policy objectives and to the wellbeing of all Australians.

The Plan will complement and add to the Government's renewed innovation agenda, which is now underway and which will be released shortly.

I believe that Australia's system of innovation and research can and should be ranked in the world's top 10. It is a worthwhile and achievable goal, and the National Research Investment Plan will help take us there.

I warmly commend this Plan and the high ambitions it conveys for our nation's future.



The Honourable Julia Gillard MP
Prime Minister of Australia

MINISTER'S FOREWORD

For Australia to participate in the global transition to knowledge and innovation based economies it is vital that we have a robust and nimble research system. To secure our future prosperity we need to be innovative and strengthen science, research and industry linkages.

This can only be achieved with a research sector that has a strong and highly skilled workforce, infrastructure to support basic and applied research and collaboration on the local, national and international scale.

The Gillard Government recognises the contribution that science and research makes toward driving innovation. Our investment in science and research improves the wellbeing of all Australians by addressing the social, economic, technological and environmental challenges we confront.

The Australia in the Asian Century White Paper recognises the importance of science and research in helping Australia seize economic opportunities in the region. Our world class research will help us compete in a region that will soon be the largest producer and consumer of goods. Scientific collaborations with our Asian neighbours will increase the flow of ideas and strengthen our knowledge base.

The National Research Investment Plan sets out a framework and process for a whole-of-government approach to science and research investment. This will ensure future government investment decisions improve the capability of the science and research sector, address key challenges and maximise the benefits that flow from research.

Ultimately, national strategic research investment creates the base for an adaptable sector that can meet the challenges of the future as well as improve the wellbeing of all Australians.

Senator the Honourable Chris Evans
Minister for Tertiary Education, Skills, Science and Research

CHAIR'S FOREWORD

Australians use the fruits of research and innovation to enrich their lives, every day of every year. Consider for a moment what life would be like without modern medicine, without the Internet, or without nutritious and dependable food. Then remember that all these things, plus many more on a much longer list, are there for us because of research and innovation.

Governments invest in research and innovation to increase productivity, increase employment and improve national wellbeing. In short, governments invest in research and innovation to improve the lives of their citizens.

Significantly, research investment also consolidates a nation's place in the world because it contributes new ideas and innovative outcomes to a world increasingly dependent on new knowledge to confront the challenges faced by humanity as a whole. With research and innovation, there is hope that these challenges can be managed; without them there is not.

The Australian Government plays a vital role in supporting our nation's research and innovation capability. It does this through:

- encouraging increased business sector research;
- setting priorities for mission-based research that improves national wellbeing;
- ensuring Australia has a strong basic research capability that drives discovery and underpins innovation;
- supporting the training of researchers;
- funding research infrastructure that cannot be provided by business or individual research organisations; and
- facilitating domestic and international research collaboration.

This National Research Investment Plan sets out a framework and a process for delivering government support in a holistic manner that takes account of the interaction between the inputs to research and coordinates investment across the whole of government. Using the framework will ensure that we know of gaps in our capability and can judge when and how to fill them. We will be able to develop our research capability in a manner that allows us to work on today's challenges while maintaining the capacity to address tomorrow's needs as they arise.

This Plan has been developed by the Australian Research Committee, comprising a senior Commonwealth Officials Group, Expert Advisory Group and Research Sector Group. I would very much like to thank the members of those Groups for their dedication to the task and their valuable contributions in shaping this Plan.

Professor Ian Chubb AC
Australia's Chief Scientist
Chair of the Australian Research Committee

CONTENTS

EXECUTIVE SUMMARY

Research and innovation make our lives better. New knowledge, technologies and innovative processes increase living standards, improve the health of our population and create more sustainable and resilient communities.

There are two main mechanisms by which research and innovation improve national wellbeing. Firstly, research is an important driver of productivity growth. New ideas enable both the business and non-business sectors to deliver better products and services more efficiently. Secondly, research helps to solve national and global challenges. New technology improves disease prevention and treatment, increases food production and helps us to protect our nation and our environment.

Business, higher education, Commonwealth, State and Territory governments and the private non-profit sector are all important contributors to research and innovation. Indeed, the business sector represents the majority of Australia's research and development expenditure, which raises the question: why should the Australian Government invest public funds in research and innovation?

The fact that business cannot capture the full economic benefit of research, and that non-business research organisations have limited resources, means that research by all sectors is likely to be less than socially optimal unless support is provided by the Australian Government. In this context, the government has a particular responsibility to sustain basic research and research that serves the public good.

Over the years, government decisions on research funding have generally been taken individually or, from time to time, as part of a larger one-off policy initiative. The Australian Government's 2011 review of arrangements for the public funding of research called for a national, strategic dialogue and better coordination of research effort and investment.

The National Research Investment Plan (the Plan) sets out, for the first time, a comprehensive national research investment planning process: a process that will enable a coordinated, whole-of-government approach to research investment that is structured to meet national needs and provide value for money. Accordingly, the Plan will support future decisions by the government in relation to the level and balance of research investment. In summary, the planning process comprises:

- the **objective** of guiding Australian Government research investment in a way that improves national wellbeing by increasing productivity and addressing Australia's key challenges;
- a framework, in the form of a **national research fabric**, that enables the development of Australia's research capacity and capability to be responsive to the needs of all sectors including business;
- a set of **research investment principles** that ensures government investments address the overall investment objective and are delivered efficiently; and
- a statement of **strategic research priorities** that enables investment to be focused on meeting the government's priorities.

With cross-portfolio and research sector membership, the Australian Research Committee (ARCom) will have the composition required to manage the research investment planning process and to achieve the necessary coordination across government.

INVESTMENT OBJECTIVE

The broad aim of this Plan is to guide future government decision making with a view to maximising the impact of research investment on Australian productivity growth and living standards. The stated objective encompasses the need to support increased productivity and competitiveness of the business sector, increased efficiency of the public sector and improved wellbeing for the Australian population as a whole.

NATIONAL RESEARCH FABRIC

The research fabric, described in this Plan, provides a comprehensive investment framework that encompasses Australia's basic and applied research capacity across the disciplines, while allowing research investment to be focused in a strategic way that addresses national challenges and contributes to increased productivity.

The research fabric enables the coordination of government investment in Australia's research capability across five key domains that underpin research on each of Australia's key challenges. This enabling capability draws upon five fundamental elements: publicly funded research, the research workforce, research infrastructure, domestic and international collaboration and business research.

The Plan seeks to align government research investment more closely with business needs by, among other things, involving the business sector in the development of enabling capability, supplying the research qualified staff business requires and ensuring business has easier access to the outputs of publicly funded research.

RESEARCH INVESTMENT PRINCIPLES

The Plan identifies seven principles that emphasise the purpose of government research investment and the nature, balance and delivery of that investment. Collectively, the principles provide a reference point for assessing the relevance and likely effectiveness of potential government research investments.

STRATEGIC RESEARCH PRIORITIES

To ensure government investment in the research fabric achieves maximum impact, effort needs to be focused on the highest priority research needs relating to Australia's key challenges.

Work conducted in 2012 to update the National Research Priorities (NRPs) concluded that, while the NRPs provided a convenient summary of the scope of Australia's research endeavour, they were not an effective mechanism for targeting government research investment. As a result, ARCom will develop a statement of more specific strategic research priorities that can be used to focus future government investment within the framework of the research fabric as a whole.

EVALUATION AND UPDATING

In managing the research investment planning process, ARCom will develop and implement a mechanism for evaluating its efficiency, effectiveness and appropriateness. In addition to measuring the excellence, academic worth and academic impact of research outputs, the evaluation process will assess the broader economic, social and environmental benefits resulting from all elements of government research investment.

This Plan describes an ongoing process for managing the Australian Government's research investment. The Plan will therefore be updated at three-year intervals, or as required.

ACTIONS

The Australian Government is implementing a national research investment planning process encompassing the actions shown below.

ACTION 1:

The Australian Government has adopted the national research fabric as a framework for research investment decision making to promote:

- a strong enabling capability in the Physical, Natural, Human, Technology and Information domains; and
- sustainable capacity in the fundamental elements, namely: publicly funded research, the research workforce, research infrastructure, domestic and international collaboration and business research.

ACTION 2:

The Australian Government has adopted the following principles for research investment.

1. Enhance productivity growth

Investment in research and innovation should result in the adoption of improved products and processes by end-users from both the business and non-business sectors.

2. Address Australia's key national challenges

Investment in research and innovation should address Australia's key economic, social and environmental challenges so as to improve the wellbeing of Australians.

3. Increase the stock of knowledge

Investment should support the discovery of knowledge that current and future generations can utilise in innovative ways.

4. Support global quality and scale

Investment should support the quality and scale of Australian research and innovation capability needed to collaborate effectively with world-leading researchers and businesses.

5. Deliver a strong, cohesive research fabric

Investment should:

- result in the quality and quantity of researchers needed by the business and academic communities;
- provide high quality research infrastructure;
- facilitate enduring collaborative relationships between researchers and end-users from both the business and non-business sectors;
- develop enabling capability in the five key domains;
- support a balance of mission-led and investigator-led research;
- support basic and applied research across a broad range of disciplines; and
- employ a mix of strategic, competitive, formula driven and entitlement funding mechanisms.

6. Create a sustainable capability

Investment should be made with a view to sustaining the long term viability of Australia's research and innovation capability. Funding for core research and innovation programs should be ongoing and predictable.

7. Be subject to monitoring and evaluation

Investment should be subject to regular, rigorous and transparent monitoring and evaluation to assess efficiency and impact. The value of the National Research Investment Plan as an investment planning process should also be subject to periodic evaluation.

ACTION 3:

ARCom will prepare a detailed plan to develop enabling capability across the five key domains. The plan will:

- identify demand by business, higher education, government and the private non-profit sector;
- identify present research capacity and capability across the domains;
- recommend action to address any identified gaps and vulnerabilities; and
- ensure that end-users from business and government are involved in the development of the plan and have access to the resulting research capability and research outputs.

ACTION 4:

Australian Government research and innovation programs will provide ongoing support for each of the fundamental elements of the research fabric: publicly funded research, the research workforce, research infrastructure, domestic and international collaboration and business research.

ACTION 5:

Proposals for additional Australian Government science and research funding programs (or substantial changes to programs) should use the framework and principles outlined in the Plan to guide decision making and to ensure the proposal can be successfully implemented.

ACTION 6:

- To provide the multidisciplinary capacity required to respond flexibly to evolving challenges, the Australian Government will continue to support a wide range of high quality basic and applied research.
- To increase the efficiency of grant allocation processes, and better support excellent Australian researchers, the ARC and NHMRC will be asked to consider options for the more widespread use of research grants of longer duration directed to individuals and teams.
- To capture the full value of the Australian Government's research investment, ARCom will provide advice on a whole-of-government approach for opening access to the outputs and data from publicly funded research.

ACTION 7:

Building on work being progressed under the Research Workforce Strategy: *Research Skills for an Innovative Future,* ARCom will:

- propose measures to help ensure the future supply of research skills can meet demand;
- examine the structural issues associated with research careers in higher education and propose measures to make these careers more attractive, including by increasing the flexibility for early to mid-career researchers to gain experience in other roles and/or sectors; and
- propose measures to provide research students with the generic skills and innovation capabilities needed to be productive in a wide range of employment contexts, including business.

ACTION 8:

- The Australian Government will consider mechanisms to provide ongoing support for major national research infrastructure as current programs are coming to an end. These mechanisms should be consistent with the principles set out in the *Strategic Framework for Research Infrastructure Investment.*
- The Australian Government will evaluate landmark research infrastructure proposals in the context of this Plan on a case by case basis, taking into account advice provided by ARCom.

ACTION 9:

- ARCom will provide ongoing advice on improving linkages and collaboration between the research sector and industry.
- ARCom will provide advice on mechanisms to support strategic international research collaboration that would not take place without government facilitation and support.

ACTION 10:

- Australian Government investment in enabling capability, and the fundamental elements of the national research fabric, should be more closely integrated with business research and the business sector's needs for innovation to support productivity growth.

ACTION 11:

- As the current National Research Priorities are broad in nature and do not provide a focus for Australian Government research investment, ARCom will prepare a statement of more specific, strategic research priorities that reflects government needs for research and innovation to replace the National Research Priorities. This statement will provide a basis for targeting government investment in the research fabric and will be updated by ARCom every three years, or as required.
- ARCom will develop a process, for consideration by the Australian Government, that enables future research funding for departments and agencies to be more closely linked with the government's strategic research priorities.

ACTION 12:

- ARCom will implement and manage the national research investment planning process.
- ARCom will establish a mechanism for evaluating the national research investment planning process.
- ARCom will update the National Research Investment Plan at three-year intervals, or as required.

1. INTRODUCTION

BACKGROUND

In 2009, the Australian Government set out a 10 year innovation plan, *Powering Ideas: An Innovation Agenda for the 21st Century*. *Powering Ideas* is a plan to build a stronger national innovation system that will drive economic growth and create a better way of life for Australians:

> This will involve investment in reform and renewal. It will involve setting priorities and strengthening coordination; improving skills and expanding research capacity; increasing innovation in business, government and the community sector, and boosting collaboration – domestic and international – across the system.[1]

In 2011, the government conducted a review of existing arrangements for the public funding of research. That review examined the degree to which the current public investment model is effective in meeting the government's policy aspirations. The review also identified opportunities to increase further the returns from the government's investment in research and innovation.

The review concluded that while there is no evidence of any significant shortfalls in the current framework for publicly funded research, there would be value in establishing a national, strategic dialogue and better coordination of research effort and investment. The review therefore recommended that:

> An Australian Research Committee of senior officials from key Australian Government departments and agencies, chaired by the Chief Scientist for Australia, be established to develop, among other responsibilities, a national research investment plan (with input from the states and territories and industry) to cover the full range of research activities, including human capital, infrastructure and collaborations.[2]

The government accepted the review's four major recommendations and announced that it would establish the Australian Research Committee (ARCom), chaired by Australia's Chief Scientist, to provide the government with integrated and strategic advice on future research investments. ARCom's initial task was to develop the National Research Investment Plan (the Plan).

1 Australian Government (2009a), *Powering Ideas: An Innovation Agenda for the 21st Century*, Commonwealth of Australia, Canberra

2 DIISR (2011a), *Focusing Australia's Publicly Funded Research Review – Maximising the Innovation Dividend*, Review Taskforce, Research Division, Canberra

TERMS OF REFERENCE

The terms of reference (Appendix A) show that the Plan is intended to support future decisions by the Australian Government in relation to the level and balance of research investment, taking into account future priorities for major strategic research investments.

The Plan aims, therefore, to provide a whole-of-government framework against which future research funding decisions can be taken. The Plan provides advice on:

- principles to guide national research and innovation investment decisions;
- the nature of the investments required to sustain a cohesive national research and innovation capability;
- the nature of the investments required to provide research capacity that meets demand from the business and non-business sectors; and
- arrangements to ensure there is appropriate prioritisation and coordination of Australian Government research and innovation investment.

The Plan covers investment in the key inputs to research and development (R&D), such as well-trained researchers, modern facilities and equipment and effective research collaboration. It also addresses investment to support the utilisation of research by business and government.

The Plan will guide future Australian Government investment decisions and ensure that such investments are balanced and complementary. Decisions relating to the management of individual government programs will continue to be the responsibility of relevant Ministers.

The terms of reference specify that the initial Plan should relate to the period 2013-14 to 2015-16, but also note that the Plan will be reviewed every three years, or as necessary, to support future decisions by the government in relation to ongoing research investment.

DEVELOPMENT OF THE PLAN

ARCom is chaired by Australia's Chief Scientist, Professor Ian Chubb AC. During development of the Plan, ARCom comprised three elements:

- a senior Commonwealth Officials Group, which was responsible for managing the development of the Plan and providing it to the government via the Minister for Tertiary Education, Skills, Science and Research;
- an Expert Advisory Group, which provided cross-sectoral expertise and guidance on the structure and scope of the Plan; and
- a Research Sector Group, comprising members from organisations responsible for delivering science and research funded by the Australian Government, which assisted in the identification of emerging research issues and needs.

Membership of the ARCom groups during the development of the Plan is shown at Appendix B.

All Australian Government departments were invited to participate on the ARCom Officials Group. This broad membership was necessary to capture the full spectrum of research and innovation issues and to develop an integrated, whole-of-government research investment plan.

Some members of the Expert Advisory Group were also members of the Research Workforce Strategy Advisory Group, the Education Investment Fund Advisory Board or the Innovation Australia Board, thereby bringing to ARCom an awareness of the issues considered by these bodies.

ARCom consulted with the Commonwealth, State and Territory Advisory Council on Innovation (CSTACI), State and Territory officials and State and Territory Chief Scientists, concerning priorities and issues that were important from a State and Territory perspective.

Bilateral and multilateral meetings were held with members of a range of industry, academic and private non-profit research organisations to ensure that their views were incorporated in the development of the Plan.

2. THE RATIONALE FOR RESEARCH INVESTMENT

HOW AUSTRALIA BENEFITS FROM RESEARCH

Australia's national wellbeing, as reflected in the health and lifestyle of the population and the security and sustainability of the environment in which Australians live, is dependent on research and innovation. Improved living standards are dependent on new, efficient technologies and processes being developed and deployed across all sectors of the economy. Figure 2.1 outlines how this occurs.

Figure 2.1: How Australia Benefits from Research

The OECD defines research and innovation in the following ways:

> Research and experimental development comprise creative work undertaken on a systematic basis in order to increase the stock of knowledge, including knowledge of man [human kind], culture and society, and the use of this stock of knowledge to devise new applications.[3]
>
> Innovation is the implementation of a new or significantly improved product (good or service), process, new marketing method or a new organisational method in business practices, workplace organisation or external relations.[4]

Importantly, the process as a whole comprises, not just the conduct of research to create knowledge and translate it into a new product, but also the taking of action to deploy or implement the new product or process. Research outputs need to be utilised by the business and non-business sectors for the gains in productivity and economic growth to be realised, and for the economic, social and environmental benefits to be experienced by Australians. Australia's research capability therefore needs to be responsive to the *demand pull* by business and government organisations seeking to create benefit from new discoveries.

New ideas enable both the business and non-business sectors to perform more efficiently and effectively. Motorised transport, telecommunications, mechanised farming and computing provide past examples of the way that research leads to innovation and improved productivity. Many of these big, society-changing productivity gains have been the result of technical research and innovation. However, non-technical innovation, such as new ways of organising and performing work, have also played a major role in lifting performance.

Innovation 'pushes out' the 'frontier' of production possibilities, thereby increasing the scope for productivity improvement and the likelihood of economic growth over the longer term. Research, particularly basic or blue-sky research, might not immediately lend itself to innovative applications or new goods and services; however, it provides a stock of knowledge that current and future generations rely on to undertake innovation.

Moreover, government investment in research can create a *virtuous cycle,*[5] with research investment creating new knowledge that helps drive innovation. Innovation, in turn, can improve the wellbeing of Australians and expand knowledge-based industries, thereby improving the government's financial position and allowing it to further increase its investment in research.

Box 2.1 provides an example demonstrating in practical terms how strategic and sustained government investment in research leads to increased research capability that enhances productivity growth and addresses national challenges, thereby contributing directly to improved national wellbeing.

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3 OECD (2002), *Frascati Manual: Proposed Standard Practice for Surveys on Research and Experimental Development*, Paris

4 OECD (2005), Oslo Manual Guidelines for Collecting and Interpreting Innovation Data, 3rd edition, OECD and European Commission, Paris

5 NHMRC (2010), *2010-12 Strategic Plan*

BOX 2.1: ICT RESEARCH IMPROVES NATIONAL WELLBEING

NICTA (National ICT Australia Ltd) is the largest organisation in Australia dedicated to ICT research. NICTA has specialised facilities to support leading edge research in key areas including computer vision, control and signal processing, machine learning networks, optimisation and software systems. Australian Government investment created NICTA, with an average of almost $50 million per year invested since 2002.

ENHANCING AUSTRALIA'S RESEARCH CAPABILITY

Around 60 affiliated students complete a PhD at NICTA each year. The total to date is more than 300 graduates, who have gained project experience and undertaken courses in ICT, commercialisation and entrepreneurship. These graduates represent about 20 per cent of Australia's total number of PhD completions in ICT each year.

An initial survey has shown that NICTA trained researchers are employed across industry (24 per cent), industrial research (19 per cent), universities (31 per cent) and government research (8 per cent). NICTA also recruits some of the best ICT researchers worldwide. More than 30 per cent of NICTA's current researchers have been employed from overseas. Of the professionals who left NICTA during 2011, it is known that at least 86 per cent remained in employment in Australia.

NICTA produces around 600 publications per year, has had 18 patents granted and more than 160 applications pending. NICTA has established eight start-up companies, with 8 - 10 potential start-ups progressing through the pipeline. Some 66 people are employed in Australia and 15 people overseas within these start-ups. These companies have raised $37.6 million in capital and earned $20.6 million in revenue (30 June 2012 figures). NICTA initiates around 50 new collaborative engagements each year and has 100-200 active engagements at any point in time.

INCREASING PRODUCTIVITY

Intelligent Fleet Logistics is an example of the way NICTA's research can increase efficiency and productivity for the business sector. Trials show that algorithms developed by NICTA for calculating the best possible transport routes reduce line-haul costs by around 9 per cent and distribution costs by between 20-33 per cent. The analysis projects a potential aggregate saving of up to $730 million per year in Australia, with widespread uptake in the transport of fast moving consumer goods. This corresponds to an impact on Australian GDP of $7.3 billion in present value terms to 2020, using the economic impact model.

ADDRESSING NATIONAL CHALLENGES

NICTA is developing improved medical implants for use in treating chronic pain. These implants will not only result in lower product costs but also improved treatment quality. Research suggests that, in 2011, chronic pain cost the New South Wales (NSW) economy $12.9 billion in health system costs, indirect financial costs and reduced wellbeing. If NICTA's implants can reduce the number of individuals in NSW with chronic pain by 3 per cent this would decrease costs associated with chronic pain by $387 million. Assuming the NSW economy represents 30 per cent of the national economy, the national decrease in costs would be $1.29 billion.

PRODUCTIVITY GROWTH

Asian countries are becoming increasingly urban, with hundreds of millions of people moving out of poverty and into the new middle classes. These changes are boosting global demand for food, energy and other resources produced by Australia, leading to increased prices for our products. At the same time, the rise in exports from Asia and the high value of the Australian dollar are placing pressure on Australian businesses in the export- and import-competing sectors. The way in which Australia responds to these issues, and manages the transition to a new economy, will determine the future living standards and wellbeing of Australians.

Australia's ability to meet the needs of its ageing population in a circumstance of economic, social and environmental stress is dependent on economic growth. As the *Intergenerational Report 2010* pointed out, economic growth is a function of productivity, workforce participation and population, and furthermore:

> With the ageing of the population reducing participation, productivity growth will be the major contributor to real GDP per person growth in Australia over the next 40 years.[6]

Extensive Australian and international research has led to a global consensus (see Box 2.2) that innovation is key to achieving the productivity gains that drive economic growth. Indeed, as the UK Government recently concluded:

> The literature on growth theory . . . is unanimous in putting innovation at the core of economic growth.[7]

Sensor Floats ready for deployment at Lizard Island
(Courtesy of the Australian Institute of Marine Science, credit Scott Bainbridge)

6 Australian Government (2010), *Intergenerational Report 2010*

7 UK Department for Business, Innovation and Skills (2011a), Economics Paper No 15 in support of *Innovation and Research Strategy for Growth*, December

BOX 2.2: INNOVATION DRIVES PRODUCTIVITY AND ECONOMIC GROWTH

Innovation drives growth and is essential for addressing global and social challenges . . . it holds the key, both in advanced and emerging economies, to employment generation and enhanced productivity growth through knowledge creation and its subsequent application and diffusion.
Organisation for Economic Cooperation and Development (OECD)[8]

Innovation is critical to Australia's growth and its preparedness for emerging economic, social and environmental challenges.
Productivity Commission[9]

In the long-term, [multifactor productivity] represents improvements in ways of doing things (technical progress), which is the ultimate source of economic growth and higher living standards.
Australian Bureau of Statistics (ABS)[10]

. . . monetary policy cannot raise the economy's trend rate of growth. That lies in the realm of productivity-increasing behaviour at the enterprise, governmental and inter-governmental levels. Improving productivity growth is just about the sole source of improving living standards, once the terms of trade gain has been absorbed. This is increasingly being recognised in public discussion, but it is important we do more than just debate it.
Glenn Stevens, Governor, Reserve Bank of Australia[11]

With an ageing population, productivity growth is the key driver of future growth prospects . . . Innovation supports productivity by creating and diffusing more efficient processes and better products through the economy.
Intergenerational Report 2010[12]

A large body of evidence shows that innovative economies are more productive and faster growing . . . They are more able to find solutions to global challenges such as reducing dependence on fossil fuels, helping people live longer and healthier lives . . . Innovative businesses grow twice as fast, both in employment and sales, as businesses that fail to innovate.
UK Innovation and Research Strategy for Growth[13]

Technical, cultural and social research is an important driver of the knowledge creation that enables innovation to take place and technical and social progress to be achieved. Investment in research and innovation will therefore be central to Australia's success in producing better products more efficiently so as to capture the benefits of the Asian century, increase workforce participation and enhance the wealth of the nation.

8 OECD (2010), The OECD *Innovation Strategy: Getting a Head Start on Tomorrow*
9 Productivity Commission (2007), *Public Support for Science and Innovation,* Research Report, 9 March
10 ABS (2010b), 1370.0 *Measures of Australia's Progress*, 2010
11 Glenn Stevens (2012), *Economic Conditions and Prospects*, Address to the Credit Suisse 15th Asian Investment Conference, Hong Kong, 19 March
12 Australian Government (2010), *Intergenerational Report 2010*
13 UK Department for Business, Innovation and Skills (2011b), *Innovation and Research Strategy for Growth*

ADDRESSING NATIONAL AND GLOBAL CHALLENGES

In addition to driving productivity and economic growth, research provides strategies for addressing many of Australia's major social and environmental challenges. Research into new technologies and processes improves the day to day lives of Australians in countless tangible ways, for example:

- health and medical research, combined with better understanding of cultural and lifestyle factors, provides improved treatments for disease, more efficient management of patients and better delivery of health services;
- research into energy and environmental issues leads to low emission industrial processes, new forms of energy generation and improved natural resource management;
- new developments in areas such as sensor technology and operations research enable better urban traffic management, marine environment monitoring and energy efficient lighting and heating systems for buildings;
- research into the nature of terrestrial, marine and atmospheric processes provides the understanding needed to manage our environment and combat climate change;
- research into advanced materials and manufacturing provides the basis for the knowledge-intensive, high value and globally competitive industries;
- research into the construction of community values, attitudes and behaviours assists in understanding adaptation to social, cultural and environmental change, with applications in areas such as immigration, sustaining regional communities, urban planning, water and energy management;
- research into telecommunications and online technology provides ready access to news, information and a range of services including electronic bill paying, online access to government services and networking opportunities;
- research into the use of new media and media literacy offers applications in the provision of online education, consumer information, policy frameworks dealing with privacy, moral rights and intellectual property, virtual forms of community, and understanding the mobile workplace;
- research into advanced data management and processing systems has applications in many areas including national security where it is integral to modern defence systems and the delivery of improved customs and biosecurity services; and
- biological and agricultural research enables increased levels of food production and the adoption of more efficient farming practices.

Working together, research and innovation not only discover the underlying factors affecting issues of importance to society but also develop and deploy products and processes that achieve improved outcomes for the nation.

INCREASED NATIONAL WELLBEING

In seeking to increase national wellbeing, a government works not only to grow the economy but also to increase the nation's environmental and social capital. Wellbeing therefore has multiple dimensions including:

- the set of opportunities available to people. This includes the level of goods and services that can be consumed as well as good health, environmental amenity, leisure and intangibles such as personal and social activities, community participation and political rights and freedoms;
- the distribution of opportunities across the population. In particular, that everyone has the opportunity to lead a fulfilling life and participate meaningfully in society; and
- the sustainability of opportunities over time. In particular, consideration of whether the total stock of society's capital including human, physical, social and natural assets can support resilient and sustainable communities.[14]

In the absence of higher productivity, the wellbeing of Australians will not just stagnate; it will decline. Australia's ageing population means that the proportion of the population in the workforce will decrease. This will cause a slowing in economic growth per capita (a common measure of living standards) and will result in substantial budgetary pressures such as increased demand for age-related payments and higher quality health services.[15] These budgetary pressures will, in turn, limit the infrastructure, services and support available to Australians.

Research and innovation are central drivers of improved economic, social and environmental wellbeing. The vision and drive of some of Australia's brightest minds are constantly at work: making discoveries, devising products that improve society and growing knowledge based businesses. All of these factors were at play with, for example, the creation of the bionic ear which led to the successful company, Cochlear Pty Ltd.

14 Gorecki, S, Gruen, D and Johnson, S (2011), *Measuring Wellbeing in Theory and Practice*, Treasury Working Paper 2011-02, September

15 Australian Government (2010), *Intergenerational Report 2010*

A COMPELLING RATIONALE

Research and innovation are critical for increasing the wellbeing of Australians. As has been argued:

- a strong research capability is an important means of increasing innovation and productivity growth; and
- research and innovation are needed to address Australia's national and global challenges.

But why should the Australian Government invest public funds in research and innovation?

There is a compelling rationale for the Australian Government to invest in research and innovation that is based on the following factors:

- in the absence of government investment, neither the business nor non-business sector is likely to conduct the level of research and innovation that Australia needs to increase wellbeing;
- government has a particular responsibility to sustain basic research capability;
- an excellent research capability strengthens Australia's role in the global community; and
- government investment in research consistently provides high economic and social returns.

The extent to which Australia embraces research and innovation will determine the wellbeing of Australians in the decades to come. If Australia is to be successful in transforming to a new economy that can meet the challenges of the 21st century, then research and innovation needs to be at the very heart of Australia's economic, industry, social, national security and foreign policy.

MARKET FAILURE AND BETTER GOVERNMENT SERVICES

As the Productivity Commission has consistently highlighted, there are two main reasons why the government should invest in research and innovation.[16] [17]

1. the existence of market failure in the form of 'spillovers', where those conducting the research are unable to capture the full economic benefit of their discoveries due to ideas being used or adapted cheaply by others. Such effects provide an incentive for the private sector to limit the amount and type of research they conduct. In this situation, additional public investment in support of R&D can provide a net benefit to the nation; and
2. governments need to invest in research and innovation to improve the products and services they offer and to better discharge their functions, as does the private sector.

In the absence of government investment in research, neither the business nor non-business sectors are likely to carry out the amount of research necessary to sustain national wellbeing.

16 Productivity Commission (2007), *Public Support for Science and Innovation*, Research Report, 9 March

17 Productivity Commission (2011), *Rural Research and Development Corporations*, Inquiry Report

The spillover effects from research should not be viewed as simply the ability of other individuals and organisations to make use of the new knowledge generated. While this is important, research generates a range of benefits for society including:

- increasing the stock of new knowledge;
- training skilled graduates;
- creating new scientific instrumentation and methodologies;
- forming networks and stimulating social interaction;
- increasing the capacity for scientific and technological problem-solving; and
- creating new firms.[18]

Government support for research provides not just new ideas, but also trained problem solvers, new methods of production and expanded networks for capturing knowledge. Economic studies often identify skilled graduates as a primary benefit that flows to firms as a result of government research investment.[19] The skills developed through research training are not restricted to application in a research career. Research training and research thinking support critical inquiry into how we can do things better and are central to the advancement of our culture and society.

> The science degree and its process of education inculcates students with skills that are invaluable for work far beyond the straightforward use of scientific content. Scientific thinking promotes innovative inquiry, it encourages a robust debate of ideas, it values scepticism and it demands critical thinking and evaluation . . . These are workforce skills that a prosperous Australia cannot do without.[20]

Government funded research also results in new instruments, technologies and methodologies[21] and provides entry points for business and non-business organisations into world-wide networks of expertise and practice.

Governments are themselves responsible for the delivery of many services including, health, education, defence, biosecurity and the management of land and marine environments. Governments need to conduct research to improve their performance of these functions. Where they partner with private firms on these matters, governments also encourage innovation from the business sector. As the UK noted in discussing the role of government in fostering technological breakthroughs:

> Many of the core technologies of the modern era appear to have their origins in mission-oriented programs that involve firms as participants but not as initiators.[22]

Science and research are also essential inputs to government policy development and program evaluation. Governments have an increasing need to systematically and effectively incorporate robust science and research evidence into the policy making process across the full range of government responsibilities.[23]

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18 Salter, AJ and Martin, BR (2001), The economic benefits of publicly funded basic research: a critical review, *Research Policy 30* (3): 509-532

19 Salter, AJ and Martin, BR (2001), The economic benefits of publicly funded basic research: a critical review, *Research Policy 30* (3): 509-532

20 Chief Scientist (2012), *Address to the National Press Club*, 23 May

21 Examples of such technologies include: whole genome sequencing, electron diffraction, the scanning electron microscope, ion implantation, synchrotron radiation sources, phase-shifted lithography and superconducting magnets.

22 UK Department for Business, Innovation and Skills (2011a), Economics Paper No 15 in support of *Innovation and Research Strategy for Growth*, December

23 DIISRTE (2012), *APS200 Project: The Place of Science in Policy Development in the Public Service*

BASIC RESEARCH CAPABILITY IS ESSENTIAL

A world-class research and innovation capability requires that Australia be excellent in basic research, applied research and the implementation of new products and processes.

Not unreasonably, a business will only conduct research where it perceives that the enterprise can capture financial benefit. As a result private investment in basic research tends to be below the socially beneficial level, leaving a major role for government in supporting basic research and research that serves the public good. Nevertheless, the business sector recognises the importance of government funded basic research in growing the stock of knowledge upon which commercially oriented, applied research depends. As 20 chief executive officers of major US corporations emphasised in an open letter to President Clinton in 1996:

> History has shown that it is federally sponsored research that provides the truly 'patient' capital needed to carry out basic research and create an environment for the inspired risk-taking that is essential to technological discovery.[24]

No nation can *free ride* on the world research system as a country will not have the necessary capability to use global knowledge and information in a meaningful way unless it is engaged in both basic and applied research. Advanced industrial countries need their own, well developed basic research capabilities in order to make use of the knowledge generated by others and to sustain technological development.[25] Basic research capability enables Australian research to expand into new and emerging research fields. It provides the level of expertise Australia needs to collaborate with leading overseas researchers and to participate in the global process of discovery and knowledge creation.

Without a depth of basic research expertise, Australia:

- will not have the early access to research findings that it needs to become an 'anticipator' of new trends and directions;
- will increasingly be a 'follower' which is forced into the position of a 'price taker', having to buy in new technology from overseas once it has been fully developed;
- will not have the depth of knowledge, and strength of research-industry relationships, needed to make effective use of new technologies and processes;
- will forego spillover benefits such as the availability of trained researchers and the development of new instrumentation and methodologies; and
- will not have the capacity to conduct basic research that impacts on unique Australian challenges such as sustaining our local terrestrial and marine ecosystems.

24 CEOs of US Corporations (1996), *An Open Letter to President Clinton*, 13 February

25 Salter, AJ and Martin, BR (2001), The economic benefits of publicly funded basic research: a critical review, *Research Policy 30* (3): 509-532

Similarly, without a capacity for applied research and the translation of research into new products and processes, Australia:

- will not have the capacity to apply basic research findings to real world problems;
- will not have the ingenuity to deploy new products and processes throughout the business and non-business sectors; and
- will not have the capacity to incorporate research findings into the evidence base for policy development.

In short, without a world-leading capacity for basic and applied research, and for the implementation of innovative solutions, Australia will be locked into a path of lower productivity and lower living standards.

A STRONGER ROLE IN THE GLOBAL COMMUNITY

An increased research and innovation capability will strengthen Australia's role within the G20 and the Asian region. It will provide the basis for deeper engagement and increased influence with our international partners on matters that underpin Australia's advocacy of policies to achieve economic growth and increased employment.

A greater research and innovation capability will allow Australia to engage more deeply with Asia's burgeoning research sector and to work with Asia in building high value products and services. It will also enable Australia to play an increased role in solving the global issue of food security.

In addition, an enhanced research and innovation capability will provide the scientific and technical workforce and expertise to deliver on Australia's goal of increasing Australia's development assistance to 0.5 per cent of gross national income.[26]

A HIGH RETURN FROM RESEARCH INVESTMENT

The Australian Government's financial support for the innovation system comprises:

- funding to run the government's own research facilities; and
- the provision of grants and/or tax incentives to other sectors to support
  - the conduct of research and innovation; and
  - the building of Australia's research capability.

As well as providing financial support for research and innovation, the government has a major impact through the design and governance of institutions and the setting of the policy, regulatory and ethical environment in which research and innovation is conducted. This can include, for example, identifying research areas of national priority, establishing institutional mechanisms to progress mission-led research and setting the intellectual property rights framework within which research and innovation occurs.

26 Senator the Hon Bob Carr (2012), *Helping the World's Poor: Implementing Effective Aid*, 8 May

Earlier studies conducted in a range of countries over the 30-year period to the mid 1990s consistently found that the rate of return on public R&D expenditure was high, and in the range of 20 to 50 per cent.[27] More recently, in seeking to measure the return from government investment in R&D, the Productivity Commission judged that the benefits are likely to be high for R&D in universities and public sector research agencies due to their orientation to public good research and their role in the development of high quality human capital for the Australian economy.[28]

The Productivity Commission further noted that a substantial part of per capita economic growth is due to factors other than labour or capital inputs. This residual source of growth is called multifactor productivity because its effect is to raise the productivity of capital and labour. Multifactor productivity includes better trained labour, technological innovation and non-technological innovation. The Productivity Commission found that, over the period 1964-65 to 2004-05, some 65 per cent of economic growth per capita could be ascribed to multifactor productivity, thereby emphasising the important role that innovation plays in driving productivity and economic growth.

In instances such as environmental R&D where gains are not measurable in the short-run, the Productivity Commission concluded that research provided a range of benefits including: increased preparedness, reduced risk, adoption of new learning by government agencies, an improved skill base and spillover benefits for business.

With regard to government programs that support increased innovation by business, the Productivity Commission concluded in 2007 that, while such activity appeared to produce net gains, the gains in this case were likely to have been smaller than for publicly conducted R&D. Since then, the government has introduced a new R&D Tax Incentive that aims to boost competitiveness and productivity across the Australian economy by encouraging industry to conduct R&D that may not otherwise have been carried out.

A 2012 study of the impact of the Cooperative Research Centre (CRC) program estimated that the program generated net economic benefit to the community which exceeded costs by a factor of 3.1, excluding the additional social and environmental impacts which were not monetised.[29] The study found that the CRC program has produced new products, processes and technologies that have already generated a direct gross impact of $8.6 billion to the economy, with at least another $5.9 billion to come in the next five years. The impacts were put through a model of the Australian economy and found that the CRC program will deliver a net contribution of $278 million per annum to Australia's gross domestic product (equivalent to 0.03 per cent of GDP per annum). The study also found that CRCs are delivering significant social and environmental benefits for Australia through improved health, environmental management practices, and high quality education outcomes.

27 Salter, AJ and Martin, BR (2001), The economic benefits of publicly funded basic research: a critical review, *Research Policy 30* (3): 509-532

28 Productivity Commission (2007), *Public Support for Science and Innovation*, Research Report, 9 March

29 Allen Consulting Group (2012), *The economic, social and environmental impacts of the Cooperative Research Centres Program*, July

INVESTMENT FOR THE LONG-RUN

The rationale for Australian Government investment in research is to ensure that both the public and private sectors can generate the level of innovation needed to increase productivity and improve living standards. This is a long-term challenge that requires a long-term commitment.[30] Research and innovation are key to the sustainability of our future society. Research investment needs to be ongoing so that we can continue to build the intellectual, physical and social capital that will be required by future generations of Australians.

Furthermore, the nature of research and innovation is such that the development of new ideas often involves long lead times and requires sustained programs of research and development. Given these long lead times, and the fact that individual businesses are unlikely to capture the full benefit of research due to the existence of spillover effects, the success of large, mission-oriented research programs will generally be dependent on continued financial support by government. Indeed, business is likely to under-invest in basic research even where the outputs from that research have the potential to underpin future growth of the sector.

These factors point to the need for a stable, sustained commitment from government to support research and innovation (see Box 2.3). Such a commitment should comprise core funding programs that are ongoing and predictable, though continued support for individual projects should be subject to periodic assessment of priority and need.

BOX 2.3: STABLE AND SUSTAINED SUPPORT FOR RESEARCH AND INNOVATION

However it is channelled, government support for innovation and R&D will be more effective if it is thought of as a long-run investment... governments that choose to provide support for R&D are likely to get better results if that support is stable, avoiding a pattern of feast or famine.
Ben Bernanke, Chairman, US Federal Reserve[31]

The long time horizons and circuitous search paths involved in radical innovations... require long-term financial commitments that are frequently beyond the ability of any profit seeking firm to undertake.
UK Innovation and Research Strategy for Growth[32]

Private investment may not take place at all in areas such as basic science, where the time horizon is long and outputs are often not immediately marketable.
Organisation for Economic Cooperation and Development (OECD)[33]

30 Australian Government (2010), *Intergenerational Report 2010*

31 Ben Bernanke (2011), *Promoting Research and Development: The Government's Role*, Conference on New Building Blocks for Jobs and Economic Growth, Washington DC, 16 May

32 UK Department for Business, Innovation and Skills (2011a), Economics Paper No 15 in support of *Innovation and Research Strategy for Growth*, December

33 OECD (2010), *The OECD Innovation Strategy: Getting a Head Start on Tomorrow*

THE GLOBAL CONTEXT

Australia needs to be a respected participant in the global research community so that we can:

- benefit from access to overseas research and expertise;
- be better able to focus international research and innovation effort on issues of importance to Australia; and
- be better able to leverage research relationships to progress broader foreign policy objectives of an economic and development assistance nature.

In 2009, Australia was responsible for producing just 3 per cent of the world's scientific research publications.[34] While this was a strong performance given the size of Australia's economy, it highlights the fact that some 97 per cent of global research occurs outside Australia.

A large proportion of global research occurs in the United States, Europe and Japan. At the same time, a number of countries, especially in the Asian region are growing their research capability at a rapid rate. By 2007, China had overtaken the United States to become the country with the largest number of researchers: 1,423,381 (full-time equivalent). In 2008, Australia's research workforce comprised 92,379 researchers.[35] [36]

To maximise the economic, social and environmental impact of Australian research, Australia must engage with the international science community and access knowledge, research expertise and infrastructure that is not available in this country.[37]

While it is imperative that Australian researchers collaborate with the rest of the world, Australia is also in competition with other countries for access to research staff, research infrastructure and inwards investment in research and innovation. Hence, if Australia is to be successful in building the research capability it needs to drive national wellbeing, it must create a positive environment for the conduct of research that is successful in attracting and retaining Australian and international researchers and investors.

A National Research Investment Plan must include investment in building and sustaining a world-class research capability and must leverage that investment by accessing discoveries made elsewhere in the world.

34 DIISR (2011d), *Australian Innovation System Report - 2011*
35 OECD (2012), *Main Science and Technology Indicators 2011-12*
36 The number of researchers per thousand workers in Australia and the United States was, though, substantially higher than in China.
37 DIISR (2011e), *Evaluation of the International Science Linkages Program*

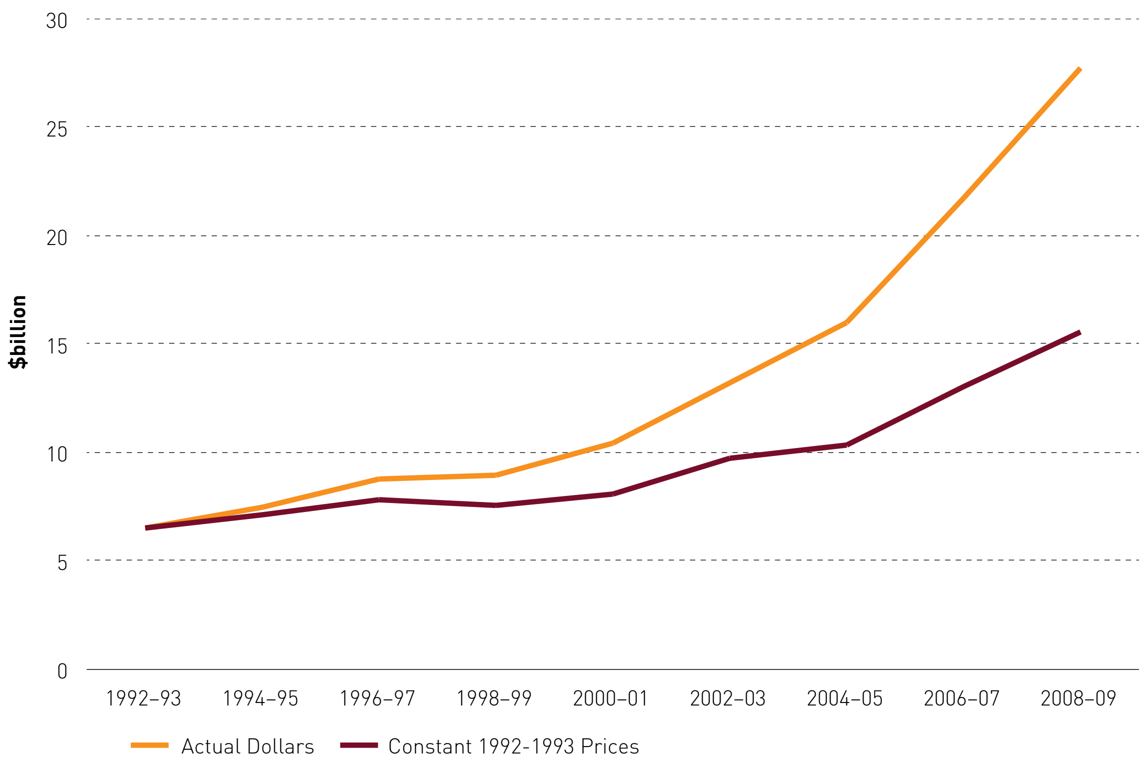
3. OVERVIEW OF RESEARCH AND INNOVATION IN AUSTRALIA

AUSTRALIA'S INVESTMENT IN RESEARCH AND DEVELOPMENT

Australia's gross expenditure on R&D (GERD) has grown strongly since the late 1990s. Between 1998-99 and 2008-09, total GERD increased from $8.9 billion to $27.7 billion (see Figure 3.1).[38] In real terms,[39] Australia's GERD more than doubled in the ten years to 2008-09.

Figure 3.1: Australian GERD from 1992-93 to 2008-09

Source: ABS (2010) Research and Experimental Development, All Sector Summary, Australia, 2008-09



38 2008-09 is the most recent year for which data are available.

39 Constant 1992-93 prices.

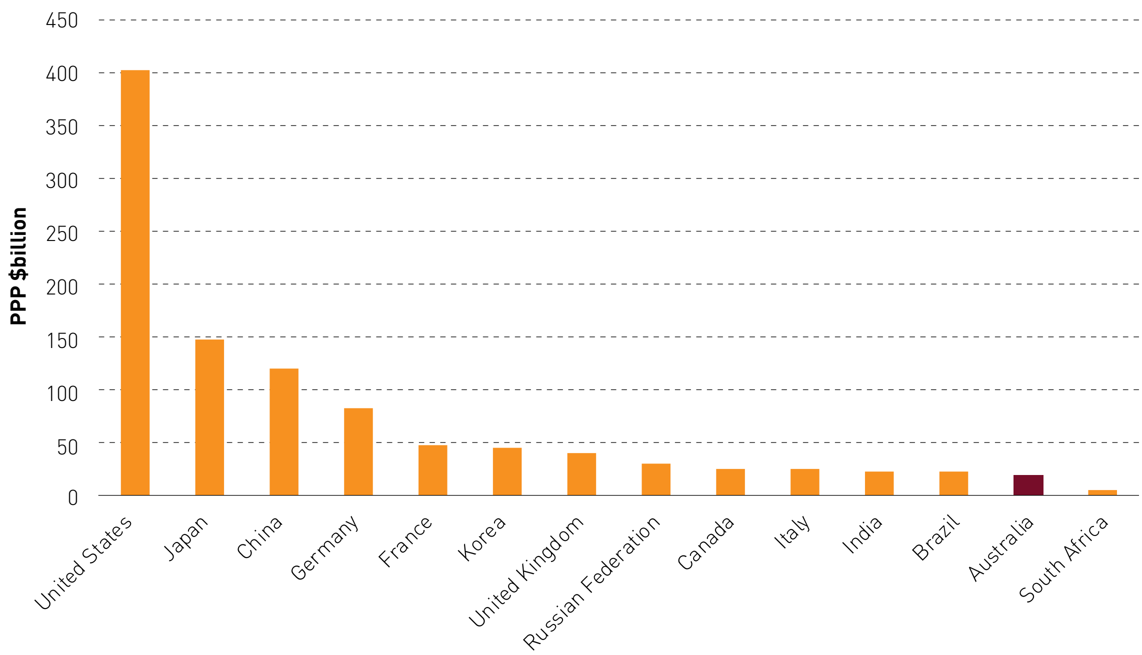
INTERNATIONAL COMPARISONS

When comparing GERD across countries, the OECD and UNESCO express figures in Purchasing Power Parity (PPP) terms to account for differences in national currencies and economic strengths. On this basis, Australia was the 15th ranked country for GERD in 2008. Figure 3.2 shows Australia's GERD in comparison with that for the top ten nations and the BRICS economies (ie, Brazil, Russia, India, China and South Africa). BRICS is a grouping of rapid growth economies that comprise over one third of the world's population. Each of the BRICS economies, except South Africa, has higher expenditure on R&D than Australia.

In 2008, Australia's research and development activity equated to 47 per cent of that for the United Kingdom, 16 per cent of that for China and 5 per cent of that for the United States.

Figure 3.2: GERD - Australia, Top Ten Nations and BRICS (2008)

Source: OECD (2011-12), Main Science and Technology Indicators UNESCO 2012 Science and Technology Report used for Brazil and India (2007 data used for India)



Consideration of a country's GERD as a percentage of Gross Domestic Product (GDP) provides a measure of national research intensity. Figure 3.3 shows Australia's research intensity against that for the top ten nations and the BRICS economies. Australia ranked 14th on this measure in 2008.

Australia's research intensity has increased over the past ten years from 1.4 per cent in 1998 to 2.2 per cent in 2008.

Figure 3.3: Research Intensity (GERD/GDP) - Australia, Top Ten Nations and BRICS (2008)

Source: OECD (2011-12), Main Science and Technology Indicators

UNESCO 2012 Science and Technology Report used for Brazil and India (2007 data used for India)

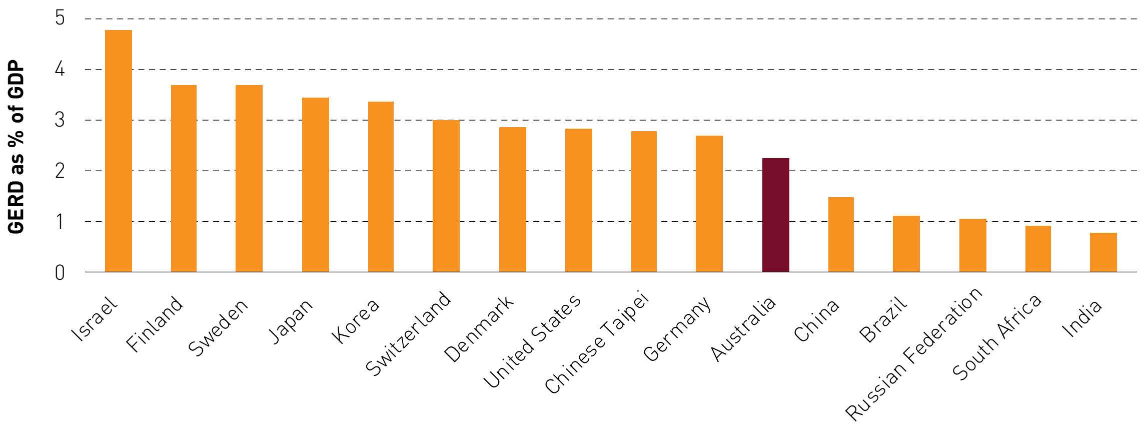


Table 3.1 shows the number of full-time equivalent (FTE) researchers, and researchers per thousand people in the labour force, for the top ten countries and Australia.
In 2008, Australia was the 13th ranked country for the number of full-time equivalent researchers.[40] Of the countries listed in the table, Australia and the United Kingdom are the only two that have fewer researchers in the business sector than in higher education.

Table 3.1: Australia and Top Ten Nations by FTE Researchers (2008)

Source: OECD, Main Science and Technology Indicators, 2011-12

Country	Rank	Researchers (FTE)	FTE per thousand labour force	Researchers in Higher Education/ Researchers in Business
China	1	1,592,420	2.5	0.24
United States[41]	2	1,412,639	9.0	*[42]
Japan	3	656,676	13.3	0.25
Russian Federation	4	451,213	11.5	0.34
Germany	5	302,467	12.5	0.43
United Kingdom	6	251,932	11.0	1.77
Korea	7	236,137	12.1	0.19
France	8	229,130	13.8	0.54
India	9	154,827[43]	0.3[44]	0.25
Canada	10	148,983	13.3	0.55
Top ten average			9.9	
Australia	13	92,379	12.0	1.93
OECD total		**4,201,255**[45]		

40 The definition of researcher is 'those involved in the conception and/or development of new products/processes', including postgraduate students. It is not dependent on qualifications held.

41 OECD data for 2007.

42 FTE Researcher data not available for the United States.

43 UNESCO data for 2007.

44 UNESCO data for 2005.

45 Composite of OECD data for 2008 (where available) and 2007 (where 2008 data not available) – therefore indicative only and not an official OECD figure.

LOCATION OF EXCELLENT RESEARCH CAPABILITY

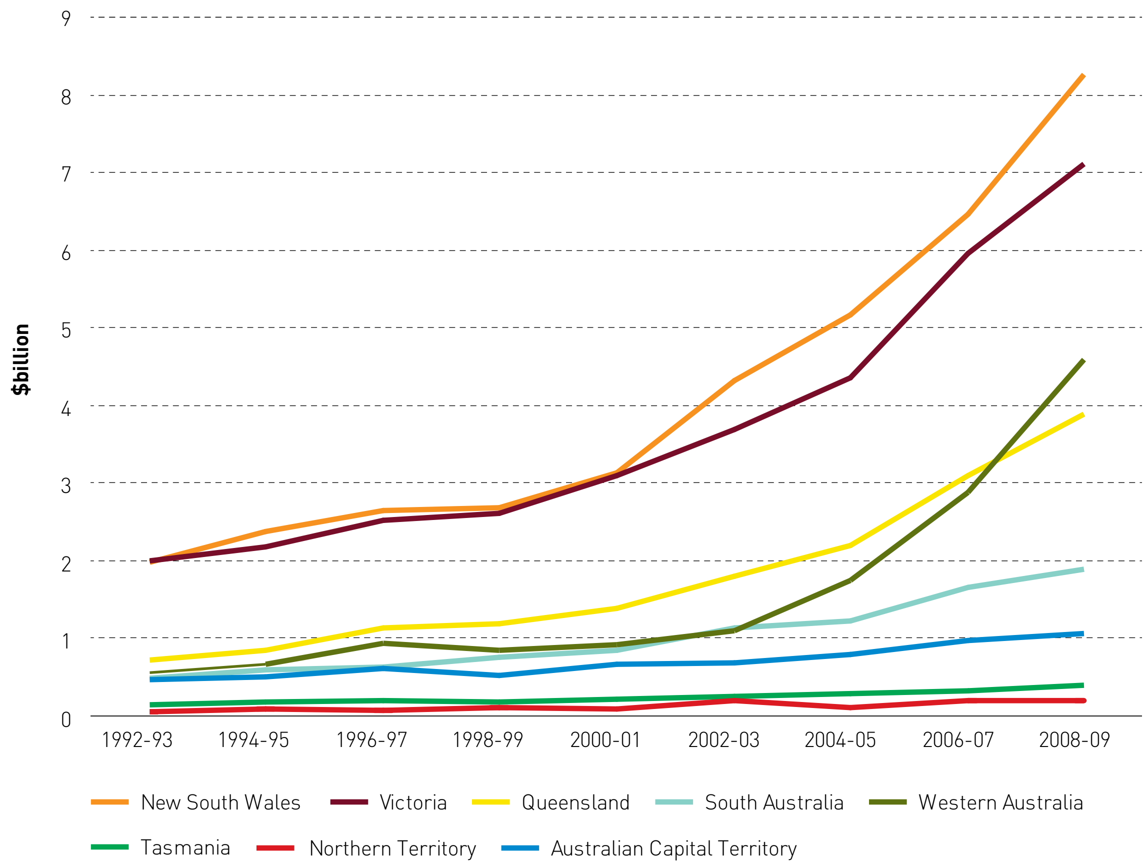
Figure 3.4 shows the trends in GERD for each State and Territory. These figures represent the total research expenditure in each jurisdiction by all sectors: business, higher education, government research organisations and private non-profit research institutes.

R&D expenditure in New South Wales and Victoria combined to represent 55 per cent of Australia's total for 2008-09, with Western Australia and Queensland providing a further 31 per cent. South Australia, the Australian Capital Territory, Tasmania and the Northern Territory accounted for the remaining 14 per cent of R&D expenditure.

Western Australia has experienced exceptional growth in R&D expenditure since 2002-03. This has been due in large part to business expenditure on R&D increasing in that State from $0.6 billion in 2002-03 to $3.6 billion in 2008-09.

Figure 3.4: GERD by Jurisdiction between 1992-93 and 2008-09

Source: ABS Research and Experimental Development, All Sector Summary, Australia, 2008-09 (2010)



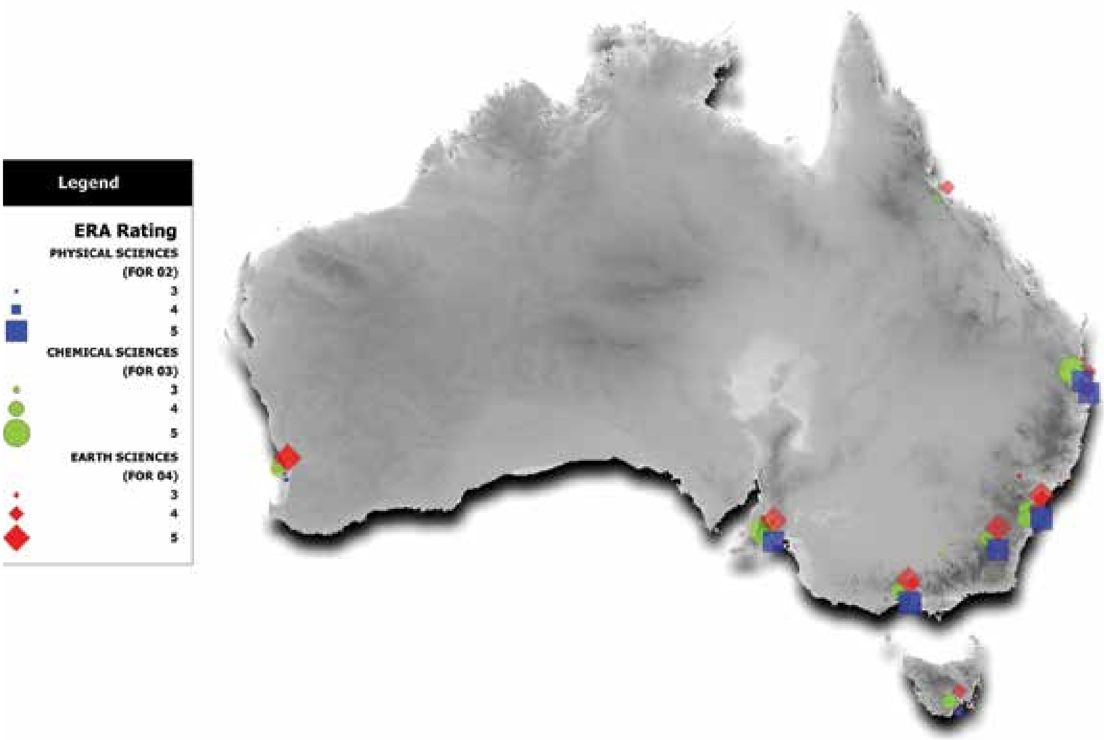
Australian Research Council (ARC) data[46] have been used to map the location of all higher education institutions[47] receiving an Excellence in Research for Australia (ERA) rating of 3, 4 or 5 in each of the 22 fields of research, where:

- 3 – evidence of average performance at world standard;
- 4 – evidence of performance above world standard; and
- 5 – evidence of outstanding performance well above world standard.

As might be expected, the resulting maps indicate a concentration of excellent university research in the five mainland State capital cities plus Canberra. In some cases, though, there is also evidence that the location of research excellence can be dependent on proximity to natural resources and related business activity. For example, Figure 3.5 shows an excellent earth science capability co-located with mining industry presence in Perth, while Figure 3.6 shows an excellent environmental science capability located in Townsville adjacent to the Great Barrier Reef. Maps for the remaining fields of research are included at Appendix C.

Figure 3.5: Location of Excellent University Research in Physical, Chemical and Earth Sciences

Source: ARC (2011), Excellence in Research for Australia 2010: National Report- Chart compiled by ANU Research Office 2012

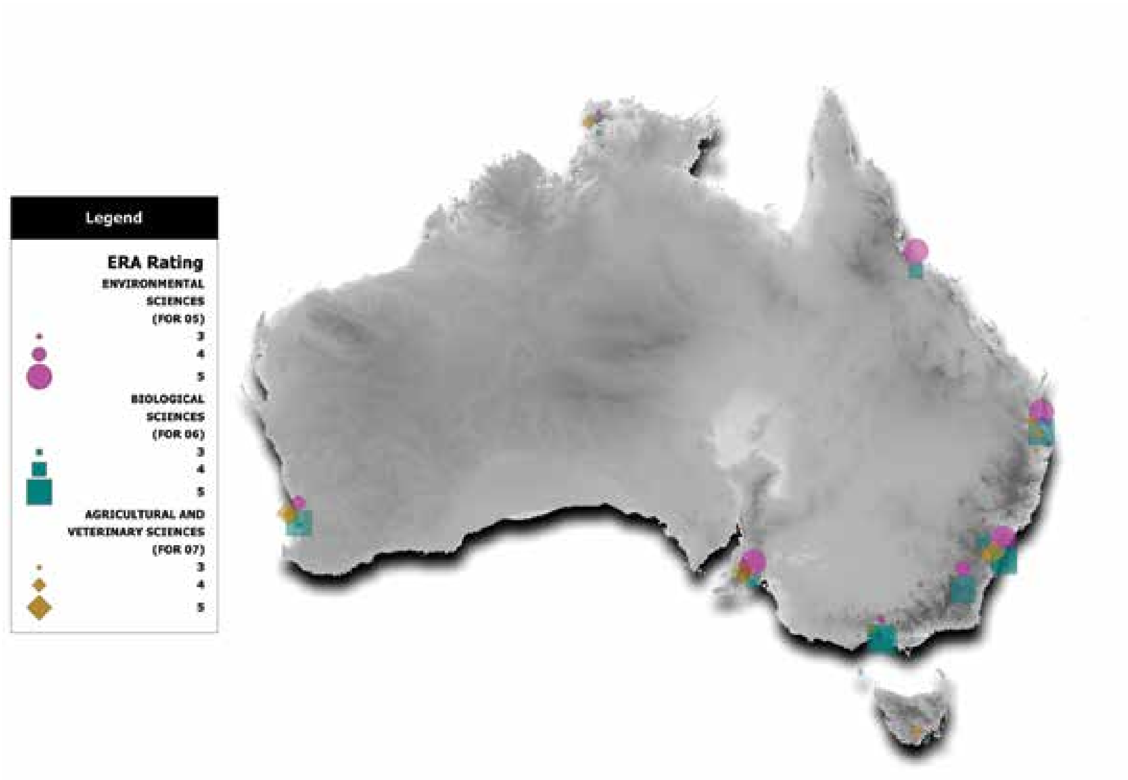


46 Australian Research Council (ARC) (2011), *Excellence in Research for Australia (ERA) 2010: National Report*

47 ERA data exclude other research organisations such as government research agencies.

Figure 3.6: Location of Excellent University Research in Biological, Environmental and Agricultural Sciences

Source: ARC (2011), Excellence in Research for Australia 2010: National Report- Chart compiled by ANU Research Office 2012

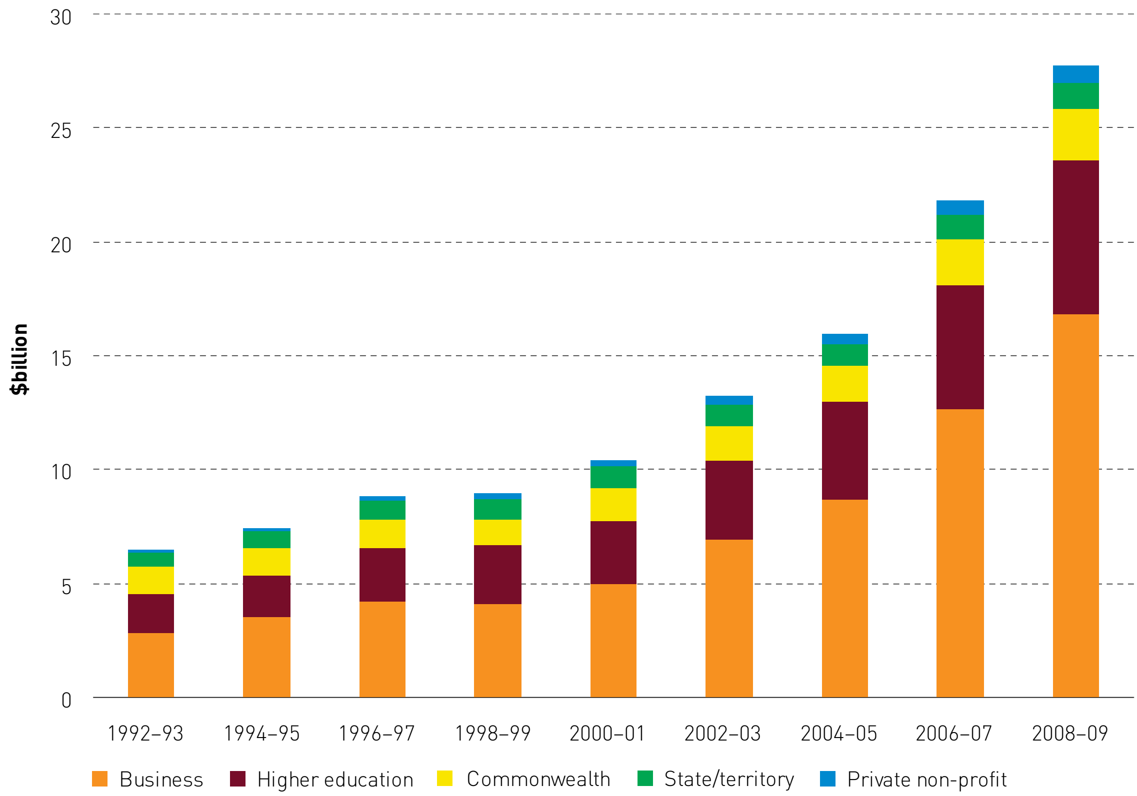


RESEARCH AND DEVELOPMENT BY SECTOR

The characteristics of R&D investment by the business, higher education, government and private non-profit sectors provide insights into the roles played by each of these sectors. The breakdown of Australian GERD by sector of performance is shown in Figure 3.7. It is clear from this Figure that the business sector has been the biggest driver of R&D growth since 2000. Further information on GERD by research sector and field of research is provided in Appendix D.

Figure 3.7: Australian GERD by Sector of Performance - 2008-09

Source: ABS Research and Experimental Development, All Sector Summary, Australia, 2008-09 (2010)



BUSINESS

Business R&D accounted for **$16.9 billion** (or 61 per cent) of Australia's GERD in 2008-09.

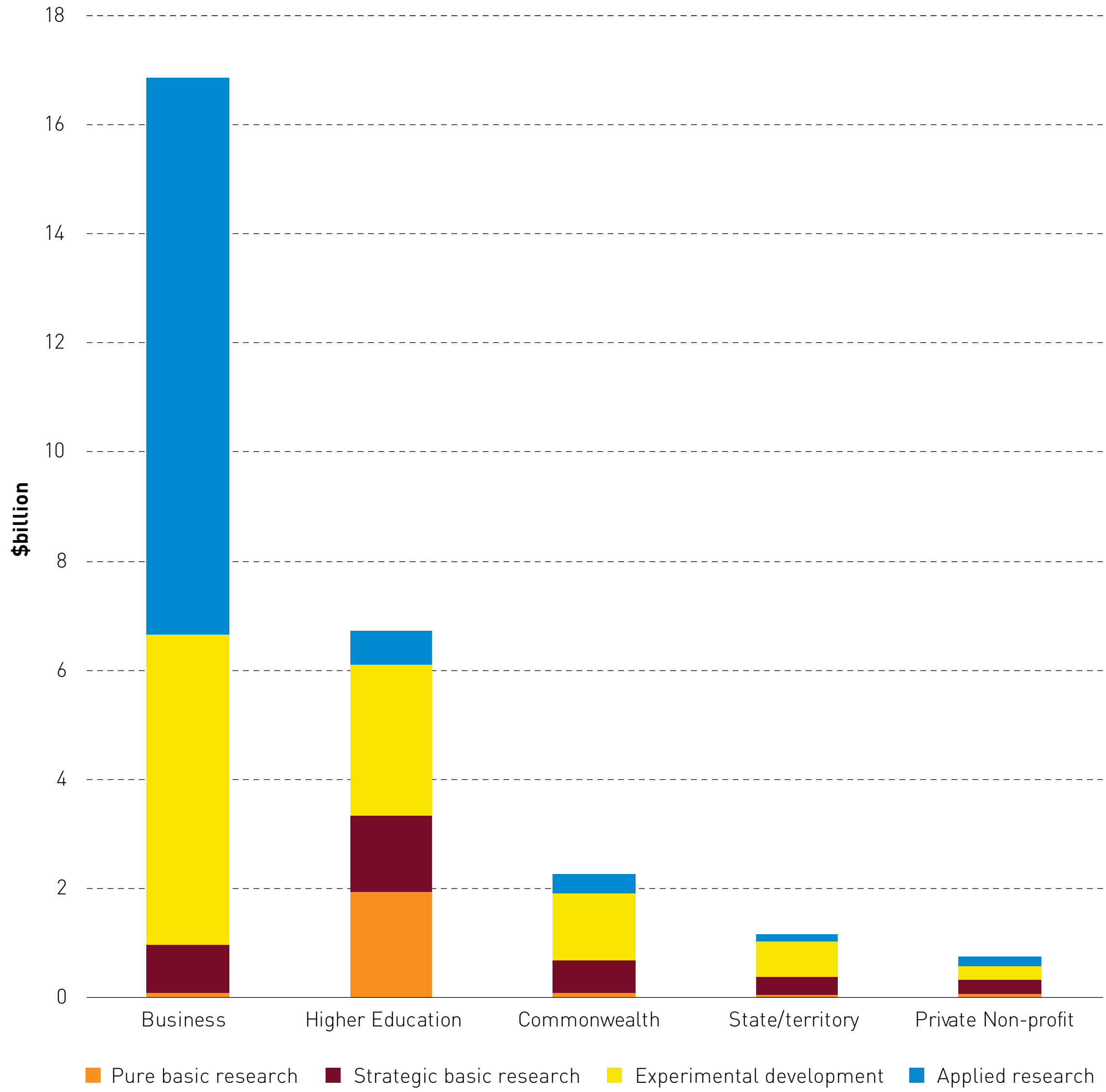
By 2010-11, business expenditure on R&D had risen to $17.9 billion although this most recent figure represented a slight fall as a percentage of GDP from 1.30 per cent in 2009-10 to 1.28 per cent in 2010-11.[48] The figures below on business R&D expenditure relate to 2008-09 to enable comparison with other sectors.

48 ABS (2012), *8104.0 Research and Experimental Development, Businesses, Australia, 2010-11*

As can be seen from Figure 3.8, some 94 per cent of the R&D undertaken by business in 2008-09 related to experimental development and applied research (ie, *applied research*), with the remaining 6 per cent relating to strategic basic research and pure basic research (ie *basic research*). As a result, business accounted for 72 per cent of all *applied research* conducted in Australia in 2008-09.

Figure 3.8: GERD by Sector of Performance and Type of Activity - 2008-09

Source: ABS Research and Experimental Development, All Sector Summary, Australia, 2008-09 (2010)



Business research has a particular focus on the following fields of research, representing more than 50 per cent of R&D expenditure in each of these fields (Figure 3.9):

- engineering;
- information and computing sciences;
- technology (which includes computer hardware, communications technology, biotechnology and nanotechnology); and
- built environment and design.

Publicly funded research is dominant in all other fields including medical, biological, environmental and earth sciences.

Figure 3.9: GERD by Field of Research and Sector of Performance - 2008-09

Source: ABS Research and Experimental Development, All Sector Summary, Australia, 2008-09 (2010)

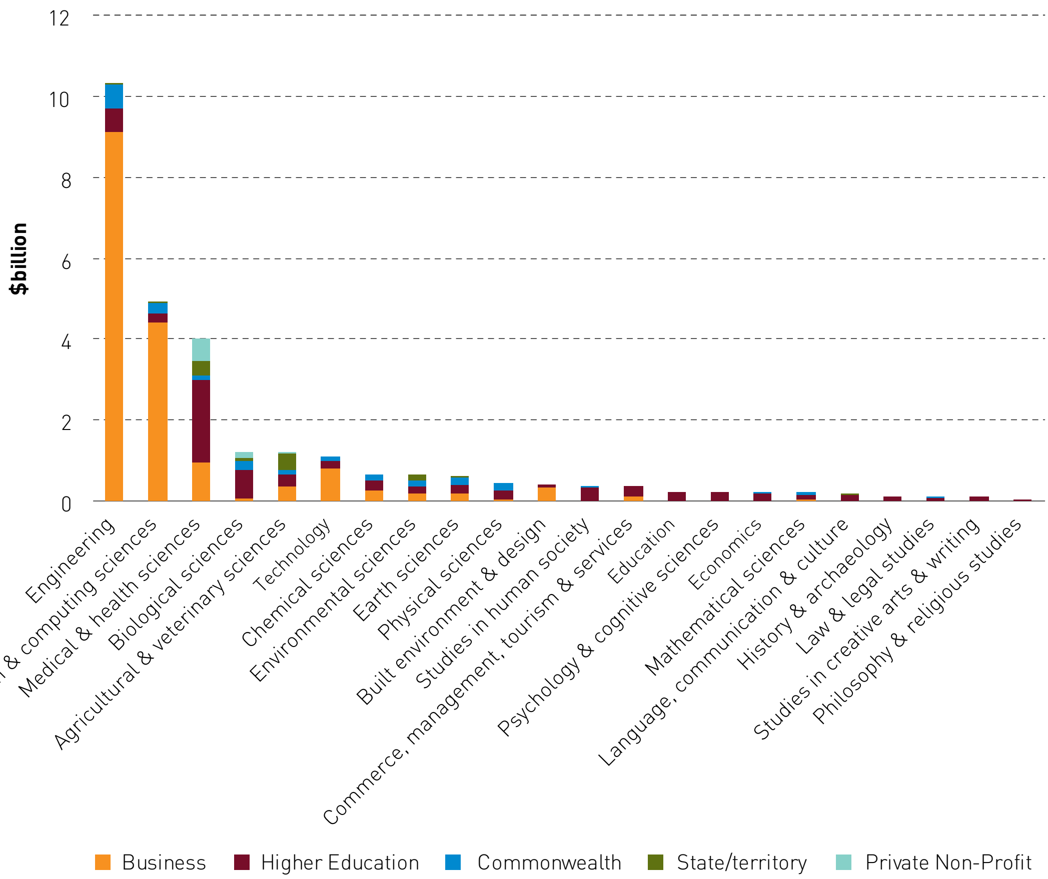
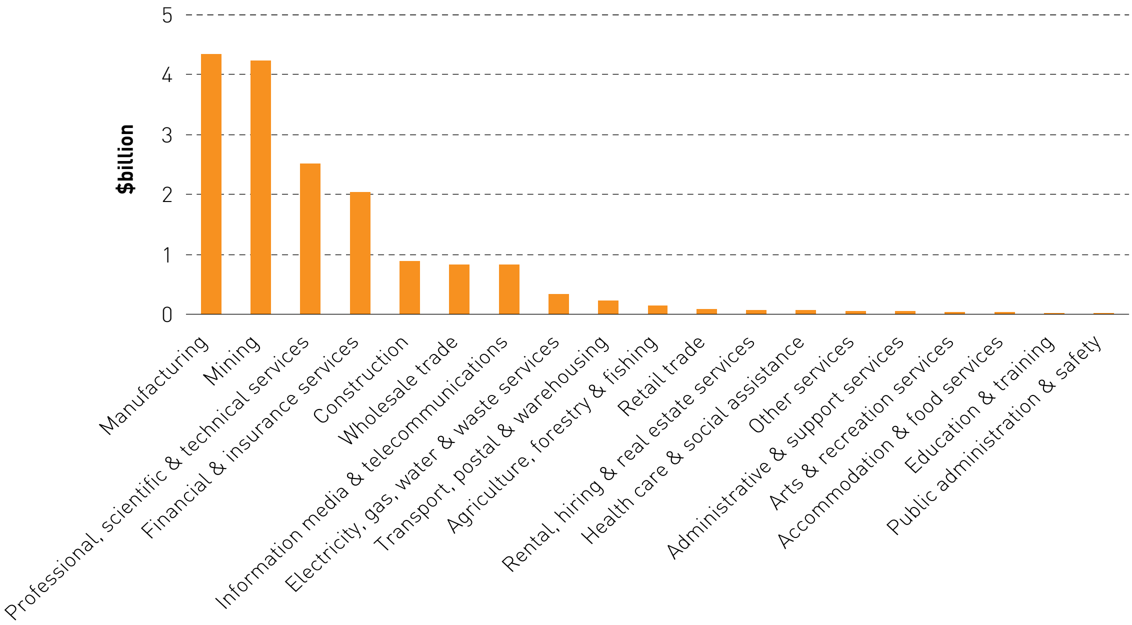


Figure 3.10 shows that over half of all business R&D is conducted by the manufacturing and mining industries, with substantial business R&D also occurring in the professional, scientific and technical services, and financial and insurance services sectors.

Figure 3.10: Business Expenditure on R&D by Industry - 2008-09

Source: ABS Research and Experimental Development, All Sector Summary, Australia, 2008-09 (2010)



While research by other sectors addresses a range of socio-economic objectives, as might be expected, the bulk of R&D undertaken by business (94 per cent) is directed toward the socio-economic objective of economic development.

HIGHER EDUCATION

The higher education sector accounted for **$6.7 billion** (or 24 per cent) of GERD in 2008-09.

Higher education was the dominant sector with regard to basic research, having 50 per cent of its R&D expenditure directed to these activities. As a result, higher education accounted for 59 per cent of all basic research in Australia, while business represented 17 per cent.

Higher education has a broad role, addressing both basic and applied research across all fields of science as well as the humanities, arts and social sciences. Higher education is also the sector primarily responsible for the delivery of research workforce training.

Business, the Australian Government and the States and Territories are each largely responsible for self funding their own R&D activity. Higher education, on the other hand, is heavily reliant on funding from the Australian Government to finance its research.

R&D conducted by the higher education and government sectors is directed toward a broad range of socio-economic objectives. Research by these sectors pursues economic development objectives, but it also addresses public good issues and matters of national preparedness. In the case of higher education, 24 per cent of research is directed toward economic development, with the remaining 76 per cent directed toward societal objectives (including health), environmental objectives and expanding knowledge (ie basic research).

AUSTRALIAN GOVERNMENT

R&D conducted by the Australian Government accounted for **$2.3 billion** (or 8 per cent) of GERD in 2008-09.

The role of government research agencies includes building scientific capacity and preparedness for the nation and conducting large-scale, mission-based research. The Australian Government conducts basic and applied research across all fields of science, plus a small amount of research related to the humanities, arts and social sciences.

While gross expenditure on R&D by the Australian Government in 2008-09 was $2.3 billion, the Science, Research and Innovation Budget Tables show that the Australian Government's total financial support for science, research and innovation in that year was $7.2 billion.[49] The difference essentially involved financial transfers from the Australian Government to the business, higher education, State/Territory and private non-profit sectors to assist them in conducting research and innovation.

Hence, while the Australian Government conducts a substantial amount of research itself, it also has a key role in providing financial support for research conducted by other sectors of the innovation system.

Commonwealth and State/Territory R&D activity is directed toward a mix of economic, social and environmental objectives. In the case of the Australian Government, 22 per cent of R&D activity is directed toward defence objectives.

STATE AND TERRITORY GOVERNMENTS

R&D expenditure by the States and Territories represented **$1.2 billion** or 4 per cent of GERD in 2008-09.

R&D expenditure by the States and Territories is much more targeted than is the case for higher education or the Australian Government. Some 88 per cent of State and Territory expenditure on research is directed toward agricultural and veterinary sciences, medical and health sciences, biological sciences and environmental sciences.

Consultation with State and Territory governments during the development of the Plan indicated that the need to achieve economic development goals in a circumstance of fiscal constraint is having an impact on how the jurisdictions focus their funding. For example, the State and Territory proportion of Australia's expenditure on agricultural and veterinary sciences research has decreased from over 60 per cent in 1992-93 to around 30 per cent in 2008-09.[50]

49 Australian Government (2012a), *Science, Research and Innovation Budget Tables: 2012-13*

50 Office of the Chief Scientist (2012a), *Health of Australian Science*, May

PRIVATE NON-PROFIT

The R&D effort by the private non-profit sector accounted for **$0.7 billion** or 3 per cent of GERD in 2008-09. In R&D terms, the private non-profit sector largely comprises the medical research institutes and 92 per cent of that sector's research is therefore directed toward improved health outcomes via research in medical and health sciences and biological sciences.

AUSTRALIAN GOVERNMENT SUPPORT FOR SCIENCE, RESEARCH AND INNOVATION

As noted above, the Australian Government conducts research and provides funds to support research by other sectors. Government support for research and innovation (summary provided at Appendix E) can be described as addressing the following six purposes:

- investment in the conduct of publicly funded research, including research by government agencies, universities and private non-profit institutes;
- development of a skilled research workforce;
- provision of excellent research infrastructure;
- strengthening of domestic and international collaboration;
- support for the conduct of research by business; and
- investment to support the commercialisation of research outputs.

An individual government program can contribute to a mix of these goals. For example, a program that might be categorised as primarily providing support for research might also contribute to workforce development, the purchase of research infrastructure, enhanced collaboration and/or commercialisation of intellectual property. Nevertheless, by identifying the *primary* purpose of each program, and then aggregating the expenditure in each category, it is possible to obtain an overview of how Australian Government research and innovation funding is directed. A summary of government funding by primary purpose is provided at Appendix F.

In broad terms, the Australian Government's 2012-13[51] allocation of $8.9 billion for research and innovation can be described in the following way:

- support for the conduct of publicly funded research (**$4.0 billion** or 45 per cent of funding) is largely allocated:
  - on a formula driven basis for higher education and rural research;
  - on a competitive basis for the funding of individual research projects; and
  - by direct allocation for the support of government research agencies and research in specific subject areas.

51 This analysis refers to figures prior to the release of the Mid Year Economic and Fiscal Outlook 2012-13.

- support for research workforce development (**$1.3 billion** or 14 per cent of funding) occurs via:
  - formula driven funding for higher education institutions and research students;
  - competitive allocation for publicly funded early career, mid-career and established researchers; and
  - NCRIS[52] style infrastructure investments that assist in developing research technicians and support staff.
- research infrastructure support (**$0.8 billion** or 9 per cent of funding) is largely allocated via:
  - formula driven funding to meet the smaller research infrastructure needs of higher education;
  - competitive rounds of the EIF[53] and HHF[54] for larger investments at higher education and other research organisations; and
  - direct EIF – Super Science funding for large, collaborative investments that reach across research sectors.
- support for research collaboration (**$0.5 billion** or 6 per cent of funding) is largely allocated on a competitive basis through programs including the CRCs[55] and ARC linkage projects:
  - and also progressed by direct EIF – Super Science (and NCRIS-style) infrastructure investments.
- support for business research (**$2.1 billion** or 23 per cent of funding) is largely allocated via tax entitlements including the R&D Tax Incentive
  - and sector specific programs such as the Automotive Transformation Scheme.
- support for commercialisation/translation (**$0.2 billion** or 2 per cent of funding)[56] is largely allocated on a competitive basis via general or industry specific initiatives.

RESEARCH OUTPUTS AND IMPACT

The number of research publications is a measure of the quantity of research being undertaken. International data are available on the number of scientific research journal articles produced by each country. As these publications represent a significant proportion of total research output, they provide guidance on the relative standing of Australian research in comparison with other countries.

52 National Collaborative Research Infrastructure Strategy
53 Education Investment Fund
54 Health and Hospitals Fund
55 Cooperative Research Centres
56 Excludes the value of venture capital tax concessions as these cannot be reliably estimated in advance.

Australia's contribution to world scientific publications is significant when compared to population size. Table 3.2 shows that, in 2010, Australia was the 11th ranked country in terms of number of scientific publications produced. Rankings of research output have been shifting in recent years, with nations such as China, India, South Korea and Brazil all moving up the rankings in terms of publication outputs.[57]

Table 3.2: Australia and Top Ten Nations by Scientific Publications (2010)

Source: SCImago. (2007). SJR — SCImago Journal & Country Rank. Retrieved August 03, 2012

Country	Rank	Publications
United States	1	502,804
China	2	320,800
United Kingdom	3	139,683
Germany	4	130,031
Japan	5	113,246
France	6	94,740
Canada	7	77,694
Italy	8	73,562
India	9	71,975
Spain	10	64,985
Top ten average		**95,130**
Australia	11	59,058
OECD total		**1,675,070**
World total		**2,406,772**

In 2011, CSIRO produced 5.6 per cent of Australia's research publications. Approximately 60 per cent of CSIRO's publications are in four fields: plant and animal science, environment/ecology, geosciences and agricultural sciences. CSIRO is a major contributor (i.e. contributes at least ten per cent) to Australia's output in each of these fields and currently is in the top ten of global institutions in three of these research fields, based on total citations.

The ARC has benchmarked the quality of Australian research in universities against world standards based on research output, measures of esteem and patents sealed.[58] At the two-digit classification level for field of research, Australia was found to have performed at world standard (Excellence in Research for Australia rating of

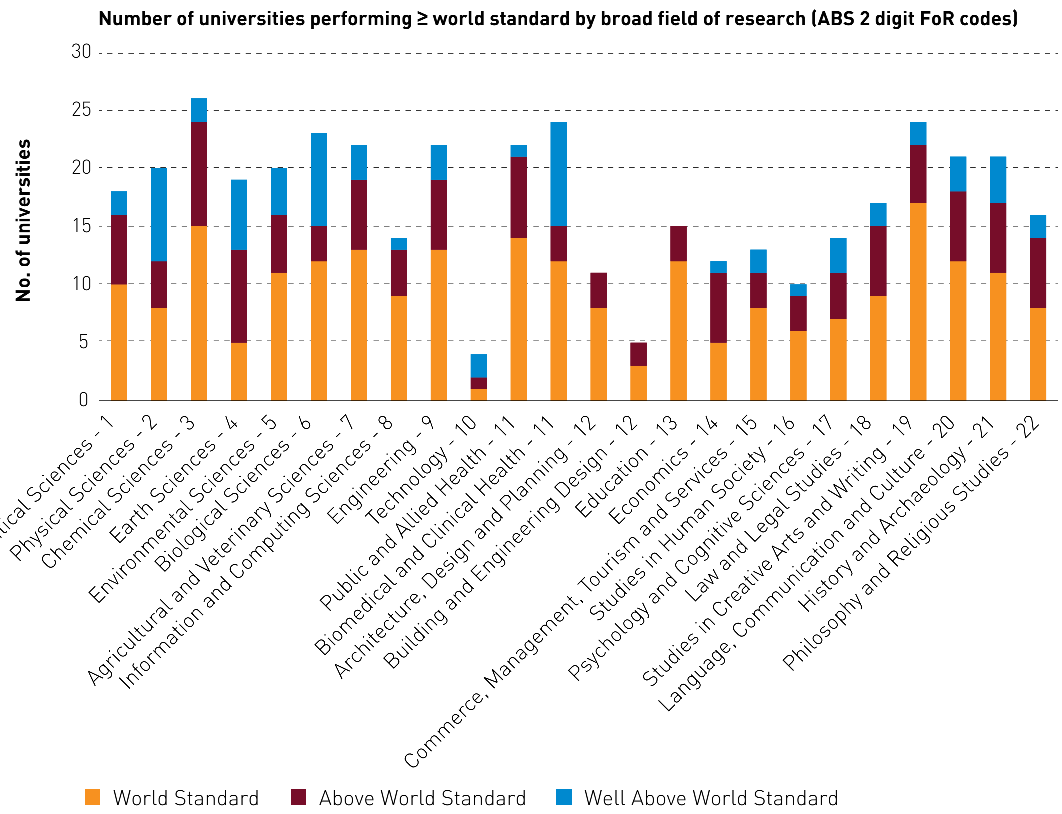
57 Office of the Chief Scientist (2012a), *Health of Australian Science*, May

58 ARC (2011), *Excellence in Research for Australia 2010: National Report*

3) or better, in 10 of the 12 fields of science-related research. Figure 3.11 shows the number of Australian universities performing at, or above, world standard by field of research (FoR).

Figure 3.11: Incidence of World Standard Performance in the ERA Evaluations, 2010

Source: ARC (2011), Excellence in Research for Australia 2010: National Report



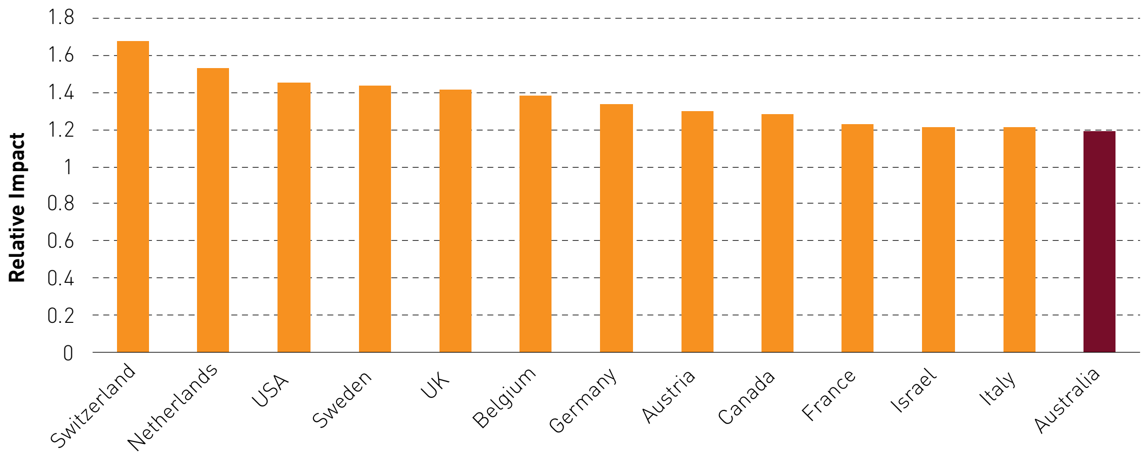
Notes: 'Architecture, Design and Planning' refers to outcomes at the two digit level across 1201, 1203, 1205 and 1299, while 'Building and Engineering Design' refers to outcomes at the two digit level across 1202 and 1204. More detailed information about the research performance of Australian universities in specific fields is provided by ERA 2010 outcomes at the level of 4 digit FoR codes.

As noted earlier, government supports research to provide a range of public benefits, including new products and processes, solutions to real world problems, and improved public policy. Such impacts can be pervasive and difficult to measure, however assessments of the broader economic, social and environmental benefits arising from research are undertaken by government research agencies (such as CSIRO and the Australian Centre for International Agricultural Research) and research funding programs (such as the Cooperative Research Centre program and the Rural R&D Corporations). At present, two proxy indicators of research impact are available in the form of the frequency with which the findings are cited in further research, and the number of patents that flow from the research.

Figure 3.12 shows that, for the period 2006 to 2010 taken as a whole, Australia was the 13th ranked nation for the relative citation impact of its scientific publications. Relative impact is the number of citations per publication expressed as a ratio of the world average. Australian publications accounted for 4 per cent of global citations over the period 2004 to 2008.[59]

Figure 3.12: Relative Impact of Publications - Australia and Leading Nations (2006-2010)

Source: InCites/ Thomson-Reuters (2012)



International co-authorship of publications increases the citation impact of research. For example, from 1991 to 2005, collaborative publications involving US or European co-authors had higher relative citation rates than Australian-only publications; and publications with both US and European collaborators had approximately three times the citation rates of Australian-only publications.[60]

Australia's research collaboration with traditional partners in North America and Europe continues to be strong. However, much faster growth in collaboration is occurring between Australia and emerging areas of scientific strength in Asia. China is now Australia's major collaborating partner in several fields of research such as mathematics, engineering and chemistry.[61]

To examine the extent of Australia's international collaboration as an indicator of trends in research impact, collaborative publications have been extracted from the Scopus database using a key word search based on sub-themes that relate to Australia's major areas of research endeavour. These publications have been plotted on a world map as 'flight paths' to indicate the collaborative research links.

Australia's international collaboration has increased strongly over recent years. For example, Figure 3.13 uses research in the area of environmental sustainability to depict the nature of this growth. While there has been strong growth with European and North American countries, there has also been strong growth with emerging countries in Asia, South Africa and, to a lesser extent, South America.

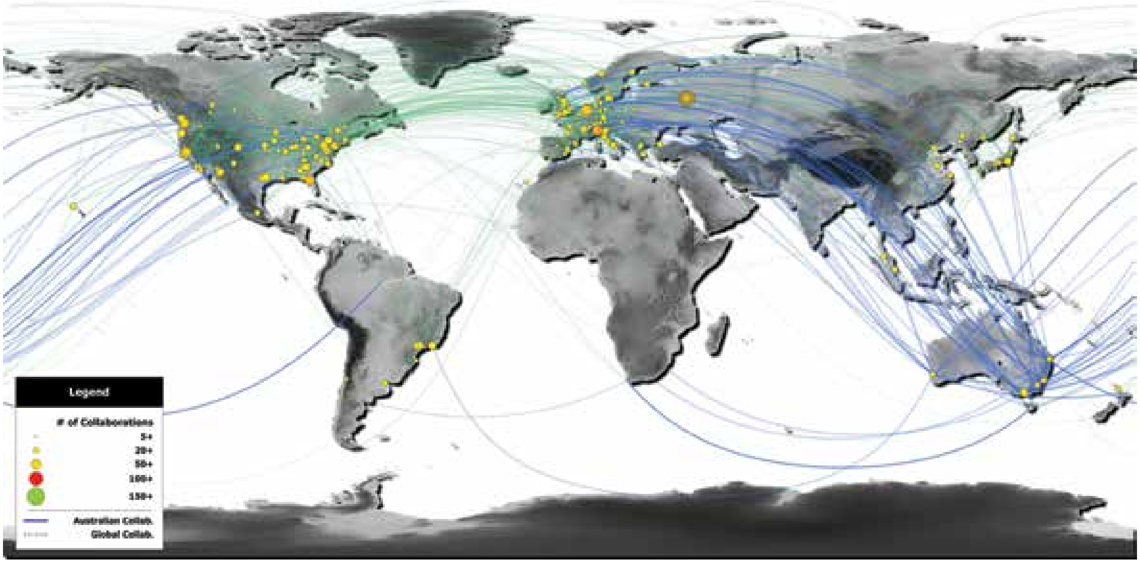
59 Office of the Chief Scientist (2012a), *Health of Australian Science*, May

60 Office of the Chief Scientist (2012a), *Health of Australian Science*, May

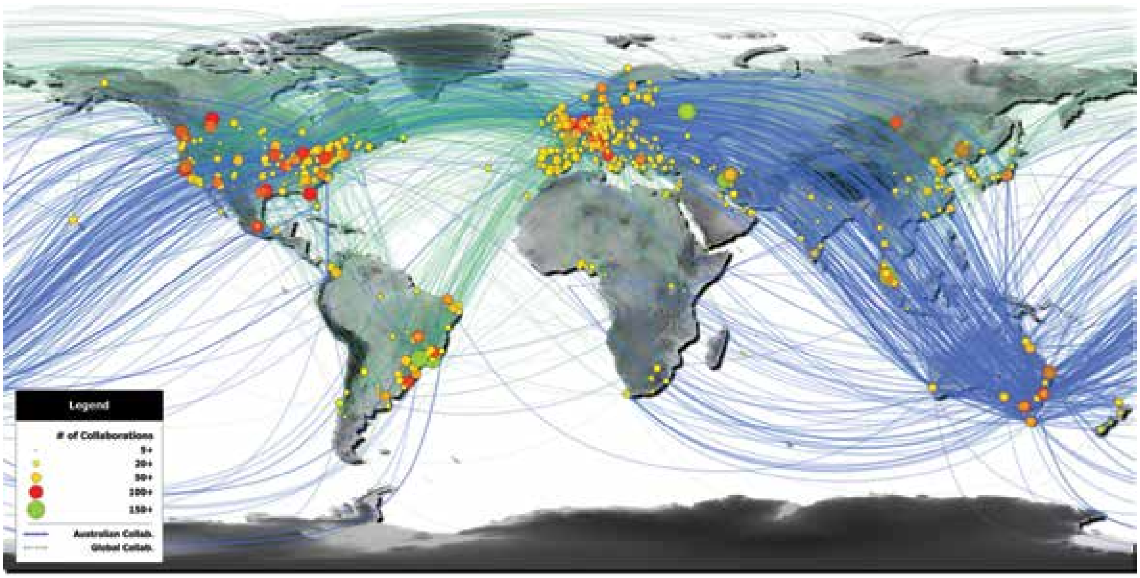
61 Office of the Chief Scientist (2012a), *Health of Australian Science*, May

Figure 3.13: Growth in International Collaboration from 2000 to 2010 – Environmental Sustainability[62]

2000



2010



62 Analysis and mapping by Australian National University Research Office, using Scopus data, 2012.
Note: The paths are colour-coded to represent instances of co-authorship; blue represents collaborations that involve Australia and green represents collaborations between the rest of the world. The size and colour of symbols represent the number of collaborations with a mapped location.

The registration of patents provides a measure of the commercial and industrial outcomes from research (see Table 3.3). The OECD reports on the filing of triadic patent families[63] (TPFs) as these involve cases where commercial return is considered likely. Some 58 per cent of world TPFs are based on invention from the US and Japan. Australia is the 18th ranked country. In 2008, China was the 12th ranked country but is likely to have entered the top ten since that date.

Table 3.3: Australia and Top Ten Nations by Triadic Patent Families (2008)

Source: DIISR (2011a), Focusing Australia's Publicly Funded Research Review – Maximising the Innovation Dividend, Review Taskforce, Research Division, Canberra

Country	Rank	Triadic Patent Families
United States	1	14,399
Japan	2	13,446
Germany	3	5,875
France	4	2,423
Korea	5	2,006
United Kingdom	6	1,621
Netherlands	7	979
Sweden	8	948
Switzerland	9	838
Italy	10	730
Australia	18	297

63 A TPF is a set of patents for the same invention filed for at the European Patent Office and the Japan Patent Office, and granted by the US Patent and Trademark Office.

4. THE DECADAL OUTLOOK FOR RESEARCH

This National Research Investment Plan is the first step in a planning process that will support Australian Government decision making over the next decade or more.

During the coming years, research activity will be much more inclusive and global than the traditional perception that enquiry and discovery is limited to the scientific elite in a small number of developed countries. The complexity and scale of research, and of the communication between researchers, will be heavily shaped by the availability of increased volumes of data and the tools to manage and analyse those data. As the President of the Canada Foundation for Innovation said:

> The iconic image of the lone scientist toiling away in an isolated laboratory . . . has given way to teams of scientists from multiple disciplines working together to address complex challenges.[64]

A NEW PATTERN OF GLOBAL ENDEAVOUR

Research is a global endeavour. There are now more than seven million researchers around the world who publish in some 25,000 scientific journals each year.[65] In the past, global research was dominated by the United States, Europe and Japan. However, the global balance is shifting with not just China, but a range of other countries in Asia, the Middle East and South America also ramping up their R&D effort:

- South Korea has pledged that its R&D spending will reach 5.0 per cent of GDP by 2012;
- China's spending on R&D has grown by 20 per cent per year since 1999 in pursuit of its goal of spending 2.5 per cent of GDP on R&D in 2020; and
- India is producing some 2.5 million science and engineering graduates each year.[66]

In response to these developments, the US and the EU have each stated an intention to increase their R&D spend to 3.0 per cent of GDP,[67] with the US having achieved a research intensity of 2.9 per cent by 2009.[68]

By 2008, Australia had increased its research spend to 2.2 per cent of GDP, making it the 14th ranked country for research intensity. However, in the absence of further increases, Australia is likely to be overtaken during the coming decade by a number of other countries.

The changing pattern of global research effort shows that achieving knowledge-intensive growth is no longer the sole prerogative of the highly developed nations.[69]
The emergence of new countries with significant research capability means that Australia will need to strengthen its collaborative relationships with these countries, while recognising that their emergence impacts on Australia's competitive position in the global research community.

64 Phillipson, E (2010), *MediNews*, The Newsletter of the Department of Medicine, The University of Toronto, April
65 Royal Society (2011), *Knowledge, Networks and Nations: Global scientific collaboration in the 21st century*, London
66 Royal Society (2011), *Knowledge, Networks and Nations: Global scientific collaboration in the 21st century*, London
67 Royal Society (2011), *Knowledge, Networks and Nations: Global scientific collaboration in the 21st century*, London
68 National Science Board (2012), *Science and Engineering Indicators 2012*, Arlington VA: National Science Foundation (NSB 12-01)
69 UNESCO (2010), *Science Report 2010, The Current Status of Science around the World*

BROADER PARTICIPATION

The key participants in research have traditionally been business and government but other players are having an increased involvement in global science. Notable among these is the impact of philanthropists and charities. For example, in 2007 the Bill and Melinda Gates Foundation's spend of US$1.2 billion on global health was almost as much as the World Health Organisation's annual budget of US$1.65 billion.[70]

The scale of research support by philanthropists can rival that by governments and this support can not only build underlying research capability but can also set research goals and steer global research effort. As a result, on a global basis, governments no longer have sole rights to the setting of goals for mission-based research. However, where the goals of governments and philanthropists align, there is the potential for results to be achieved much more quickly than would otherwise have been the case.

Another player with an increased involvement in global research is the ordinary citizen. Members of the public have increasing access to scientific information and data and increasing opportunity to participate in the research process. In fields including biodiversity monitoring and astronomy, web portals and data repositories are being established to capture observations made by citizens that can then be used by professional scientists.[71]

Greater interaction between researchers and the broader population can lead to a variety of benefits including:

- increased understanding and acceptance within the community of the process of scientific observation and discovery;
- increased access by the community to research data and information;
- increased interest by young people in research as a result of their direct participation in research projects; and
- increased capacity to capture field data for use by professional researchers.

A structured approach to community involvement in research data collection has the potential to increase the level of science literacy in the community and increase the number of young people with an interest in research as a career.

70 Royal Society (2011), *Knowledge, Networks and Nations: Global scientific collaboration in the 21st century*, London

71 European Union (2010), *Riding the Wave: How Europe can gain from the rising tide of scientific data*, Final Report of the High Level Expert Group on Scientific Data, October

INCREASINGLY MOBILE

Researchers take a global perspective when making decisions about where to study and work and often choose locations outside the country in which they were raised. A recent National Bureau of Economic Research (NBER) study of researchers from 16 countries who worked in biology, chemistry, earth and environmental sciences and materials research found that, with virtually no variation across countries, researchers identified the following issues as the primary reasons for coming to work in another country:

- the opportunity to improve future career prospects; and
- outstanding faculty, colleagues or research team.[72]

Australia is successful in attracting researchers from elsewhere, with the recent NBER study finding that 44.5 per cent of researchers (in the fields examined) were immigrant scientists.[73] Some 21.1 per cent of this foreign workforce was from the UK, with 12.5 per cent from China. Of the 16 countries studied, Australia's level of foreign research workforce was third only to Switzerland and Canada.[74]

As shown in Section 3, some 26 per cent of Australian higher degree by research completions in 2009 involved overseas students. Training foreign researchers in Australia has the benefit that a proportion of those researchers will choose to stay in Australia to work, while others who choose to work elsewhere will have established relationships with Australian researchers that are likely to be enduring.

The best researchers want to work with the best research teams no matter where they are located and they are willing to move countries to do so. Any medium-sized country will need to make the most of this workforce mobility to strengthen its research capability and linkages.

INCREASINGLY CONNECTED

Researchers are in constant communication with other researchers, from their own country and from around the globe, via informal, researcher-driven exchanges that enable the sharing of scientific insight, knowledge and skills. As the impact of collaboration on research outcomes becomes more widely recognised, and research itself becomes more global, the nature and extent of these exchanges will continue to increase. As the Royal Society observed:

> Policy makers have not always recognised the importance of these linkages to quality and to the direction of science, tending to emphasise research investment to the detriment of developing policies that support and foster such networks.[75]

By 2008, less than 26 per cent of global research papers were the product of one institution working alone, and more than a third had multiple nationalities sharing authorship. Between 1996 and 2008, the proportion of the world's papers produced with

72 National Bureau of Economic Research (2012), *Foreign Born Scientists: Mobility Patterns for Sixteen Countries*, Working Paper 18067, May

73 Defined as having lived elsewhere at the age of 18 years.

74 National Bureau of Economic Research (2012), *Foreign Born Scientists: Mobility Patterns for Sixteen Countries*, Working Paper 18067, May

75 Royal Society (2011), *Knowledge, Networks and Nations: Global scientific collaboration in the 21st century*, London

an author from more than one country increased from around 25 per cent to over 35 per cent, and this trend shows no sign of abating.[76] In 2010, over 40 per cent of Australian scientific publications were co-authored with overseas collaborators.[77]

The power of collaboration, the expansion in the range of significant players in global research and the emergence of new communication technologies will collectively drive an increasing level of connection among researchers. Technology will enable researchers to connect not just in the exchange of ideas and information, but also in the conduct of research itself. Researchers will be able to share data sets and tools across the globe and to access shared workspaces in a way that breaks down the traditional barriers of distance.

DATA DRIVEN

> In one day, a high-throughput DNA-sequencing machine can read about 26 billion characters of the human genetic code. That translates into 9 terabytes – or 9 trillion data units – in the course of one year; alongside it is a wealth of related information that can be 20 times more voluminous. The total data flow: more than 20 new US Libraries of Congress each and every year. That is from one specialised instrument, in one scientific sub-discipline; enlarge that picture across all of science, across the world, and you start to see the dimension of the opportunity and the challenge presented.[78]

As data become cheaper to produce, the challenge is to make the best possible use of the material collected. The central importance of data management to the effectiveness of research has been known and highlighted for some years. In 2006, the Prime Minister's Science, Engineering and Innovation Council (PMSEIC) Data for Science Working Group reported on the vast amounts of data being generated from scientific research, observational projects, instruments, national and international collaborations, data mining and analysis.[79] Among other things, the Working Group recommended that there be open access to publicly-funded scientific data and that mechanisms be developed to enable the discovery, access and re-use of data.

By 2010, a submission to the European Commission emphasised that information and communication technologies are the most transformational factors in science today and proposed the development of an e-infrastructure that supports the seamless access, use, re-use and integrity of data.

In Australia, significant progress has already been made in establishing such an e-infrastructure, notably via a range of related initiatives funded under the NCRIS program and the EIF Super Science program. As a result, Australia is moving toward an environment where unmanaged and underutilised data sets can be transformed into managed, connected and findable data sets that researchers from all sectors can discover, access and re-use.

76 Royal Society (2011), *Knowledge, Networks and Nations: Global scientific collaboration in the 21st century*, London

77 Office of the Chief Scientist (2012a), *Health of Australian Science*, May

78 European Union (2010), *Riding the Wave: How Europe can gain from the rising tide of scientific data*, Final Report of the High Level Expert Group on Scientific Data, October

79 PMSEIC Working Group on Data for Science (2006), *From Data to Wisdom: Pathways to Successful Data Management for Australian Science*, December

Australia is also making data collected using public funds openly accessible for re-use by other parties. The Australian Government 2.0 Taskforce concluded that public sector information should be open, accessible and re-usable, suggesting that it should be free, based on open standards, easily discoverable, understandable, machine-readable and freely re-usable and transformable.[80]

Similar principles are increasingly underpinning policies on research publications and research data, with more and more research institutions and research funding organisations introducing open access policies. The UK has recently confirmed its support for open access to research publications and unveiled a new open access policy.[81]

A recent study has estimated that the benefits to Australia as a result of the Australian Bureau of Statistics (ABS) having made publications and data freely available are likely to outweigh the costs by as much as a factor of five.[82] The free availability of geospatial data by government agencies, which contributes to the growth and prosperity of major industries, was estimated to provide an even higher return than was the case for ABS data.[83]

Australia's participation in major, data-intensive scientific projects such as the Square Kilometre Array radio telescope will help to keep Australia at the forefront of international data management practice by requiring the development of new tools for data transmission, storage, collaboration, processing and analysis. Australia's ongoing ability to lead the world and make unique and major contributions to key research areas will rely on continued investment in eResearch infrastructure and the associated systems, skills and services.[84]

COMPLEX, INTERRELATED ISSUES

All the big national and global challenges are interdependent and interrelated as can be seen in the interaction between climate change, water, food, energy and national security, population change and biodiversity loss.[85] [86] [87] This complexity will require researchers from different fields of research, and different disciplines, to work together to explore the nature of the issues and the possible adaptation and mitigation strategies.

Increasingly, important research depends on the convergence of life, physical and engineering science disciplines in interdisciplinary areas such as bioinformatics, nanobiology, tissue engineering and biomaterials.[88]

80 Government 2.0 Taskforce (2010), *Engage: Getting on with Government 2.0*, Department of Finance and Administration

81 Research Councils UK (2012), *RCUK announces new Open Access policy*, media release, 16 July

82 Houghton, John (2011), *Costs and Benefits of Data Provision*, Report to the Australian National Data Service, Centre for Strategic Economic Studies, Victoria University, September

83 Houghton, John (2011), *Costs and Benefits of Data Provision*, Report to the Australian National Data Service, Centre for Strategic Economic Studies, Victoria University, September

84 DIISR (2011c), *2011 Strategic Roadmap for Australian Research Infrastructure,* September

85 PMSEIC Working Group (2010a), *Challenges at Energy-Water-Carbon Intersections*, October

86 PMSEIC Working Group (2010b), *Australia and Food Security in a Changing World*, October

87 Royal Society (2011), *Knowledge, Networks and Nations: Global scientific collaboration in the 21st century*, London

88 MIT (2011), *The Third Revolution: The convergence of the Life Sciences, Physical Sciences and Engineering*, January

A further ingredient for success will be the bringing together of scientists and social scientists from multiple disciplines who can offer new, and complementary, perspectives on the matters being addressed. It will also be necessary to involve business, government and non-profit organisations who understand how the research outputs can be implemented and utilised.

Given the interrelated nature of the issues and participants in the innovation process, governments are moving away from the linear concept of starting with basic research and ending up with innovation, towards a more complex, systemic notion of innovation.[89] This new approach recognises the need to resource interconnected, multidisciplinary research teams that are engaged with end-users while still conducting the basic research necessary to underpin the development of ideas.

Plant Accelerator Smart House (Courtesy of the Australian Plant Phenomics Facility)

89 UNESCO (2010), *Science Report 2010, The Current Status of Science around the World* and UK Department for Business, Innovation and Skills (2011a), Economics Paper No 15 in support of *Innovation and Research Strategy for Growth*, December

90 Heuer, R-D (2012), *If I Ruled the World*, Prospect, 22 June, www.prospectmagazine.co.uk

91 European Organization for Nuclear Research (CERN)

92 Positron Emission Tomography (PET)

93 Magnetic Resonance Imaging (MRI)

CASE STUDY: MEDICAL IMAGING – PHYSICISTS, CLINICIANS AND BUSINESS[90]

I used to think that innovation was a linear process: basic science provided the knowledge and applied science turned it into something useful. But since becoming director general of CERN[91], I've been forced to refine my ideas. Innovation is a virtuous circle linking basic to applied science. The development of PET[92] scanners to diagnose medical problems is a case in point.

The idea for PET came from the medical community, but the "P" of PET stands for positron—a particle of antimatter. Detecting particles of antimatter is a forte of particle physicists. In the 1970s, one of the first prototype PET scanners was built in collaboration between CERN and Geneva's University Hospital, and contributed to the development of commercial PET scanners. This happened because the techniques of particle physics turned out to be relevant to medicine, and the physicists were quick to spot the link. From there, industry took over the research and development, and our particle physicists went back to contemplating the universe.

A decade later, experiments demanded better particle detection, so physicists teamed up with industry to develop crystal detectors with unprecedented sensitivity. This turned out to be just what the PET industry needed, so those crystals found their way into the latest scanners.

Fast-forward ten more years, and particle physics needed to use crystal detectors inside a strong magnetic field. Electronics companies had not developed the necessary chips, but with a nudge from the particle physics community, they soon did. Physicists' needs were satisfied, and the medical imaging industry seized the new technology for scanners that give the functional information of a PET scan with the structural information of an MRI[93] scan.

This story has run for decades, and will probably run for many more. It's no accident that a publicly-funded research organisation is the common thread. CERN is a privileged place for basic science, thanks to the foresight of those who founded it 57 years ago. If all basic science could be carried out on this model—international, collaborative and open, with a stable public sector funding structure—our progress would be assured.

COORDINATED EFFORT

Research has traditionally been driven from the bottom-up, by individual researchers and via informal communication and collaboration. While this investigator-led approach to research will continue to be an essential underpinning of a flexible, creative research capability, the scale and scope of many research questions requires a more coordinated effort.

Many national and global challenges require a breadth of expertise and collaboration, specialised facilities and sustained research effort that can only be achieved with a degree of focus and a concerted program of capacity building. In these circumstances, effective research and innovation will require a deliberate policy of building global, multidisciplinary communities of interest who have access to the best data and analytical tools, and who can translate research into national benefit.

Building critical mass in areas of national importance is vital to ensuring Australia is able to harness the research effort to achieve increased productivity and national wellbeing.

FUTURE LEVEL OF RESEARCH INVESTMENT

Figure 4.1 indicates that, in 2008,[94] research expenditure by each of the leading dozen nations in the world exceeded 2.5 per cent of GDP. Australia's research intensity of 2.2 per cent was behind these leading countries but ahead of many other developed and developing nations.

Globally, the level of research activity is set to grow significantly over the coming decade. While Australia has not set a target for research intensity, a range of other countries have placed a policy priority on increasing their research capacity and have articulated national targets for research intensity. Table 4.1 shows that many of these countries are aiming to lift their R&D expenditure to 3.0 per cent of GDP, or more.

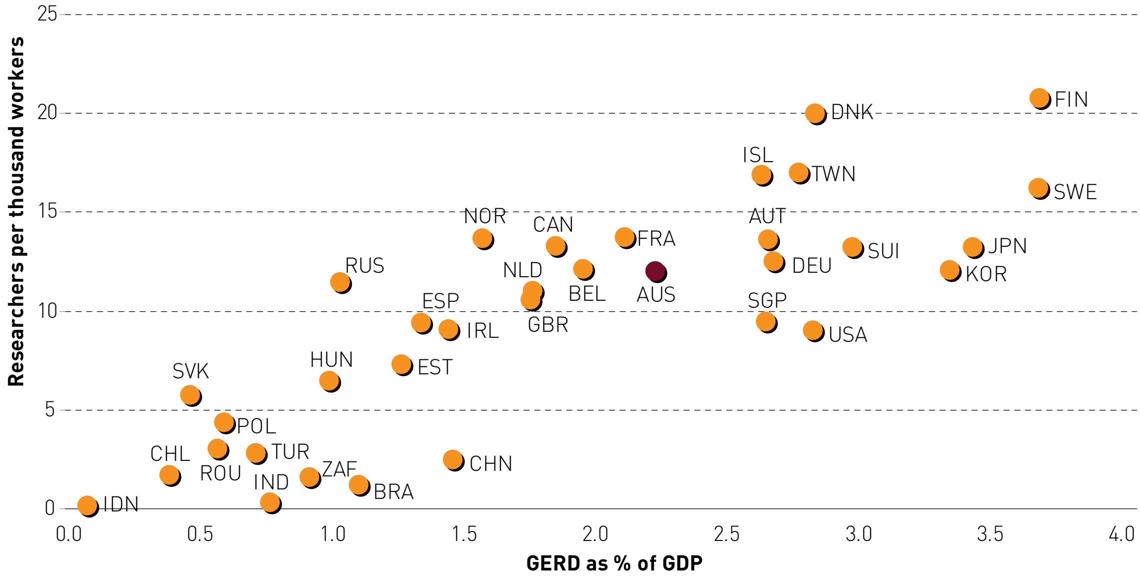
As a medium sized country with only some 30 per cent of its research workforce in the business sector, Australia will need to develop the scale and scope of its research capability so that it can engage with, and harness, this growing global research endeavour in a way that creates benefit locally for our nation.

94 Figures are based on a comparison with Australia's most recent data, which relate to 2008.

Figure 4.1: Number of Researchers by Research Intensity (2008)

Source: OECD (2011-12), Main Science and Technology Indicators

UNESCO 2012 Science and Technology Report used for Brazil (2008 data), India (2005 data), Indonesia (2009 data) and USA (2007 data)[95]



95 In 2008, Israel's research intensity was 4.8 per cent. Research workforce data are not available for Israel.

Table 4.1: Research Intensity Targets

Source: OECD Science, Technology and Industry Outlook 2012

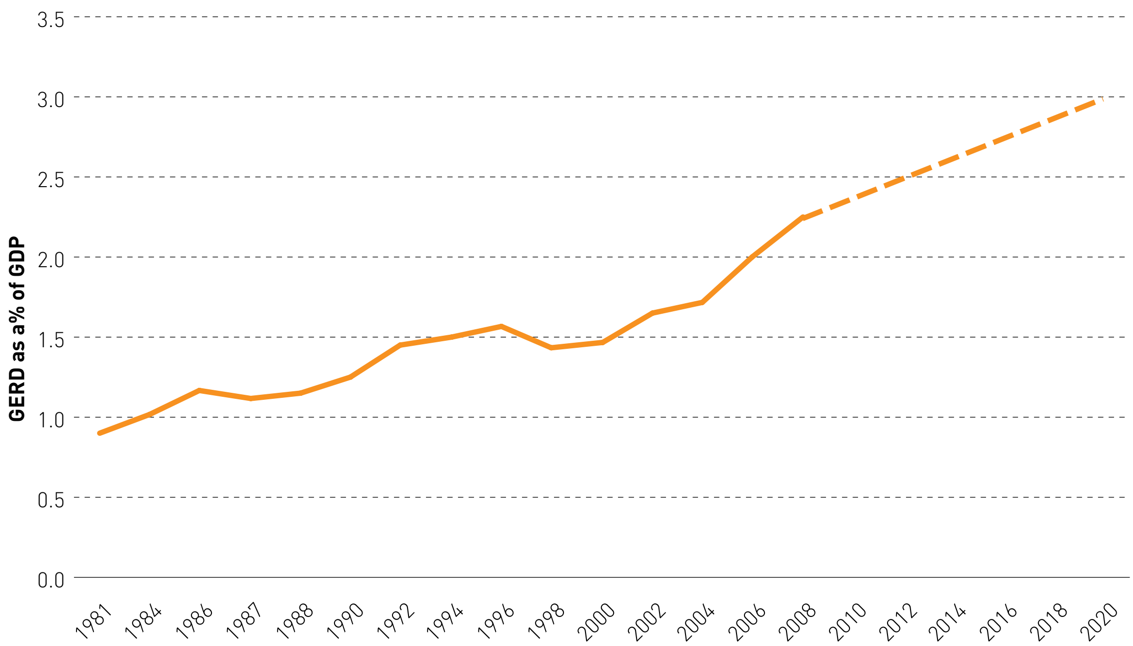
Country	Target (GERD as a % of GDP)	Target Date
Korea	5.0	2012
Finland	4.0	2020
Sweden	4.0	2020
Japan	4.0	2020
Austria	3.76	2020
Denmark	3.0	2020
United States	3.0	indefinite
Germany	3.0	2020
France	3.0	2020
Slovenia	3.0	2020
Belgium	3.0	2020
EU27	3.0	2020
Norway	3.0	indefinite
Estonia	3.0	2020
Portugal	3.0	2020
Spain	3.0	2020
Turkey	3.0	2023
Czech Republic	2.7	2020
Netherlands	2.5	2020
China	2.5	2020
Ireland	2.5	2020
United Kingdom	2.5	2014
Russian Federation	2.5	2015
Luxembourg	2.3 – 2.6	2020
India	2.0	
Greece	2.0	2020
Hungary	1.8	2013
Brazil	1.8	2014
Poland	1.7	2015
Italy	1.53	2020
Slovak Republic	1.0	2020
Colombia	0.5	2014
Chile	0.4 – 0.8	indefinite

Australia's research intensity by all sectors has been increasing over the decades, from 0.9 per cent in 1981-82 to 2.2 per cent by 2008-09, with much of this increase being driven by growth in business sector R&D which accounted for 61 per cent of GERD in 2008-09.

Despite various changes in economic fortune, industry structure and government policy, Australia's research intensity has achieved growth of 251 per cent over the twenty-eight years to 2008-09. Continuation of this trend would see Australia's research intensity approach 3 per cent by 2020-21 (see Figure 4.2).

Figure 4.2: Australian Research Intensity

Source: OECD Main Science and Technology Indicators 2012



5. AUSTRALIA'S RESEARCH FABRIC

The Australian Government's research investment will be most effective in meeting the needs of the nation if it is set within a comprehensive planning framework. This section describes a research investment framework for Australia.

NATIONAL AND GLOBAL CHALLENGES

Since 2002, the Australian Government has articulated a set of National Research Priorities (NRPs) that seek to maximise the economic, social and environmental benefits of research to Australia. The government's 2011 review of publicly funded research recommended that the NRPs be updated and refined.[96] In the course of this process, however, it became apparent that the NRPs were being asked to perform multiple functions including: acting as a statement of national and global challenges that publicly funded research is intended to address, guiding future research investment and providing a reporting framework for capturing the public benefits arising from past research investments. As these functions can be better performed by establishing a comprehensive planning framework based on the National Research Investment Plan, use of the NRPs will be discontinued, following the development of strategic whole-of-government research priorities.

In the course of developing this Plan, input was sought from a range of parties, including the ARCom Groups, on the key challenges facing Australia in the coming decade (see Box 5.1). These challenges provide a starting point for developing an investment planning framework and for identifying more detailed research priorities within each of these challenges. These challenges, together with insight gained from consultation on refreshing the NRPs, will be incorporated in future work by ARCom.

BOX 5.1: AUSTRALIA'S KEY CHALLENGES

Environment: marine, terrestrial, atmospheric;

Resources: minerals, petroleum, fisheries, forestry, water;

Security: biosecurity, cybersecurity, critical infrastructure, disaster management;

Communities: demography, regional, Indigenous, built environment, transport;

Health: disease prevention, treatment, service delivery;

Food: production, technology, processing, security;

Energy: clean technologies, sustainability, distribution; and

Competitive industries: business processes/services, innovative technologies, advanced manufacturing.

96 DIISR (2011a), *Focusing Australia's Publicly Funded Research Review – Maximising the Innovation Dividend*, Review Taskforce, Research Division, Canberra

The challenges listed in Box 5.1 align broadly with the NRPs, and with various studies that have sought to identify the major challenges that will drive Australian and global research during the next ten or twenty years.[97] In broad terms, the *megatrends* identified by these other studies relate to demographic change, health, the environment, natural resource management including energy and food production, technological change and information and communication technologies (ICT).

In addition to these issues, the list in Box 5.1 emphasises some additional concerns such as the challenge of national security including research into cyber security and Australia's preparedness to respond to politically motivated violence.[98]

Another challenge identified is that of increasing the competitiveness of our industries. This issue is taking on particular importance as the mining boom and the rising economic power of Asia place pressure on existing Australian industries. Elevated terms of trade, rapid growth in the Asian region and ongoing technological change are having a profound influence on the Australian economy, leading to significant structural change.

In fact, issues such as the Asian century, climate change and Australia's growing and ageing population combine in complex ways to drive each of the challenges identified above.

The urbanisation of Asian countries is driving massive growth in demand for food, energy and other goods and services. At the same time, Asian countries are increasing their economic output and their capacity to export to Australia and other countries outside the Asian region.[99] These changes are creating massive opportunities for Australia while heightening many of the national challenges outlined above.

If unabated, climate change will impact on the amount of water available for primary production, for secondary industries and for our urban communities while at the same time creating market opportunities for eco-industries. Extreme weather events, and their consequences, will become more commonplace in the form of droughts, storms, floods, bushfires and coastal inundation.

The growth and ageing of the population will impact on urban amenity and infrastructure, the adequacy of water supplies, the level of greenhouse gas emissions, the environment, biodiversity and the demand for health and aged care services. As a result, it will increase the difficulty in addressing a range of national challenges.

The challenges that Australia will face over the coming decade are complex, multifaceted and have no single solution. The challenges are inter-dependent[100] as is evident from the linkages between, for example, conservation of the environment and the global search for food security. The challenges emerge, combine and change over time, adding further to their complexity. Australia therefore needs a flexible research capability that can be mobilised, focused and re-focused as necessary to help address problems and increase wellbeing.

97 For example, ICSU(2011), *ICSU Foresight Analysis: Report 1 International Science in 2031 – exploratory scenarios*, December, and CSIRO (2010), *Our Future World – An analysis of global trends, shocks and scenarios, Draft*, March

98 Australian Government (2009b), *The National Security Science and Innovation Strategy*

99 Australian Government (2012), *Australia in the Asian Century - White Paper*, October

100 AAD (2011), *Australian Antarctic Science Strategic Plan 2011-12 to 2020-21*, March

SETTING AN INVESTMENT FRAMEWORK

Australia's research investment needs to provide a strong, sustainable capability in basic and applied research that can increase productivity and address Australia's key challenges. This capability needs to be built on research excellence across the spectrum of research disciplines, and needs to enable Australian researchers to draw on high quality, focussed and nationally co-ordinated support for their research.

ENABLING CAPABILITY

In order to achieve the government's aspirations for research endeavour, enabling capability needs to be brought together in a number of key areas, or domains, and further developed through an integrated and strategic approach. Capability is defined in this context as the combination of workforce, infrastructure and collaboration required to undertake research across a particular range of endeavour. Considering these needs at a domain level, rather than for a specific field of research, gives increased coordination of investment and supports sustainable, long-term research capability that is multidisciplinary in nature.

The development of enabling capability will ensure Australia has a national research capability which is broad at its base, of sufficient scale, and which can be targeted and focussed to address key challenges. Enabling capability will provide the flexible underpinning needed to respond to Australia's challenges as they evolve over time.

Five domains have been identified in which a coordinated approach is needed to develop strong, sustainable capability:

- the Physical domain;
- the Natural domain;
- the Human domain;
- the Technology domain; and
- the Information domain.

The scope of each domain is described in Section 7. All of these domains are relevant in addressing each of Australia's key challenges. In that sense, the domains are interlinked not only with each other, but are also interlinked in the way they contribute to addressing Australia's challenges.

FUNDAMENTAL ELEMENTS

A number of fundamental elements combine to provide the research capacity upon which the enabling capability depends. These fundamental elements are:

- publicly funded research;
- research workforce;
- research infrastructure;
- domestic and international collaboration; and
- business research.

In addition, Australia needs the capacity to translate research outcomes into national benefit through the commercialisation of new inventions and the deployment of improved government products and services.

Table 5.2 describes the nature of the fundamental elements which include expertise and resources located across the business, higher education, government and private non-profit sectors. Collectively, these elements need to provide a strong capacity for creating knowledge through basic discovery, as well as a capacity for developing novel products, processes and services. Development of these elements is an ongoing task, but once a strong and sustainable research capacity is established it can be directed to a mix of short and long term research questions as required.

A number of mechanisms[101] currently used by the Australian Government to support each fundamental element are listed in Table 5.2.

Table 5.1: Fundamental Elements

Element	Key Australian Government Support Mechanisms
Publicly Funded Research: includes basic and applied research capability within Commonwealth, State and Territory agencies, universities and private non-profit institutes	■ Funding for government research agencies, eg CSIRO, DSTO, ANSTO ■ ARC and NHMRC research grants ■ Sustainable Research Excellence in Universities ■ Matching of rural R&D levies ■ Research performed within departments and portfolios, eg ABARES, BITRE
Workforce Development: includes the training of researchers and research support staff, and the creation of attractive career pathways in research	■ Research Training Scheme ■ Australian Postgraduate Awards ■ ARC and NHMRC Fellowship programs
Research Infrastructure: includes the provision of local, national and landmark infrastructure	■ Funding via EIF (including Super Science) and HHF ■ Research Infrastructure Block Grants ■ ARC and NHMRC infrastructure programs ■ NCRIS (terminated June 2011)
Domestic and International Collaboration: includes the development of enduring collaborative relationships among research sectors, end-users and international researchers	■ Cooperative Research Centres program ■ ARC and NHMRC linkage schemes ■ Rural R&D Corporations, ACIAR [102] ■ Joint Research Engagement program ■ Australia-India Strategic Research Fund ■ Australia-China Science and Research Fund ■ International Science Linkages (terminated June 2011)
Business Research: includes basic and applied research capability within the business sector	■ R&D Tax Incentives ■ Researchers in business

101 Many of these programs support more than one fundamental element.

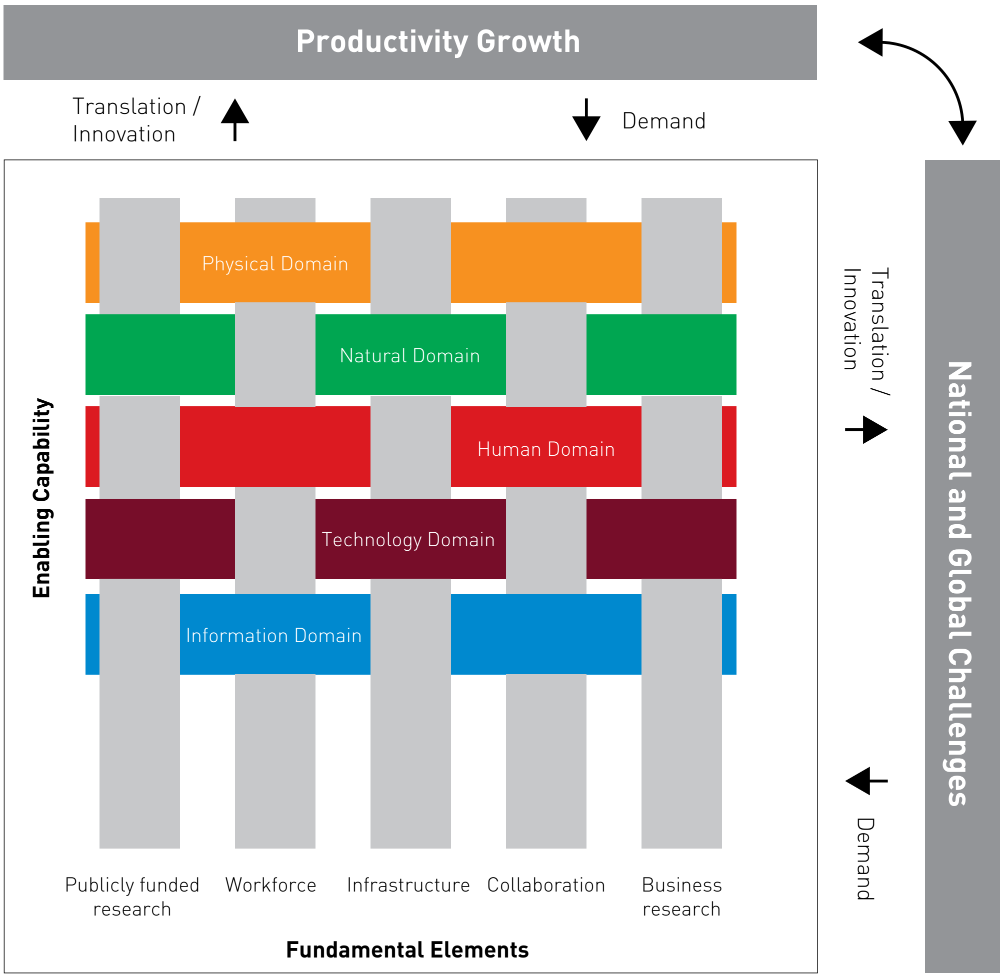
102 Australian Centre for International Agricultural Research

Australia's capacity to translate research findings into new products and services in the business sector is supported by initiatives including the venture capital tax concessions and industry specific commercialisation programs.

THE RESEARCH FABRIC

By interweaving the fundamental elements with enabling capability in key domains, it is possible to conceive of the research system at its highest level as a *research fabric* (see Figure 5.1). This provides a comprehensive investment framework that underpins Australia's basic and applied research capacity across the disciplines, while allowing research investment to be focused in a strategic way that addresses national challenges and contributes to increased productivity.

Figure 5.1: Australia's Research Fabric



The research fabric represents the full spectrum of research endeavour across all sectors, from discovery to the translation of knowledge into products and services for national benefit. The elements of the fabric are interlinked and interdependent and are founded on a strong discipline base.

The research fabric comprises the resources and expertise devoted to research by all sectors: business, higher education, government and the private non-profit sector. The fabric is therefore a national asset that can be utilised by business to increase competitiveness, by higher education and the non-profit sector to create knowledge and by government departments and agencies to deliver better services and better informed policies.

The fabric provides a basis for linking research effort across the sectors and with end-users. This coordinated, national research effort can then achieve the quality and scale of activity needed to engage closely with excellent research teams in other countries.

The goal for the Australian Government is to deliver its research investment in a way that both strengthens the overall national fabric and enables the research conducted across all sectors to contribute strongly to improved national wellbeing.

Adoption of the research fabric as an investment planning framework will coordinate Australian Government investments and avoid unnecessary duplication, while also providing the flexibility needed to adjust the emphasis of Australia's research endeavour as new avenues of enquiry emerge or as new areas of need arise.

ACTION 1:

The Australian Government has adopted the national research fabric as a framework for research investment decision making to promote:

- a strong enabling capability in the Physical, Natural, Human, Technology and Information domains; and
- sustainable capacity in the fundamental elements, namely: publicly funded research, the research workforce, research infrastructure, domestic and international collaboration and business research.

Further discussion regarding the domains and each of the fundamental elements is provided in Sections 7 and 8 respectively.

6. INVESTMENT OBJECTIVE AND PRINCIPLES

The broad aim of the National Research Investment Plan is to guide future government decision making so as to maximise the impact of research investment on Australian productivity growth and living standards. As the Future Fund Board of Guardians has noted in its Statement of Investment Policies:

> A common characteristic of successful investment organisations is that they are able to clearly define their investment objectives and articulate principles that they will follow in seeking to achieve their objectives.[103]

The National Research Investment Plan's objective and principles are set out below.

UNDERLYING DRIVERS

The following drivers underpin the Plan objective and principles:

1. Government investment in research and innovation increases national wellbeing by lifting productivity and economic growth.
2. Government investment in research and innovation increases national wellbeing by addressing Australia's key challenges.
3. Government's role in research and innovation is to:
   - show leadership by establishing the policy, regulatory and ethical framework within which research and innovation occurs;
   - fund and coordinate the conduct of research, especially public good research, by government agencies;
   - provide financial support and incentives for the conduct of basic and applied research and innovation by other sectors; and
   - provide financial support to other sectors for the development of Australia's research capacity including its workforce, infrastructure and domestic and international collaboration.
4. Appropriately structured government investment in research and innovation consistently provides a high return.[104] [105] [106]

An effective government research investment strategy should develop Australia's overall research fabric, emphasise priority areas for investment and increase innovation and productivity growth across all sectors of the economy.

103 Future Fund (2012), *Statement of Investment Priorities*, February

104 Productivity Commission (2007), *Public Support for Science and Innovation*, Research Report, 9 March

105 Productivity Commission (2011), *Rural Research and Development Corporations*, Inquiry Report

106 Salter, AJ and Martin, BR (2001), The economic benefits of publicly funded basic research: a critical review, *Research Policy 30* (3): 509-532

Such an approach should encourage the business sector to increase its investment in research, increase productivity in existing industries and lead to the development of new industries. It should help to address key national challenges including managing the health of an ageing population, responding to threats from new and emerging diseases, increasing food production and predicting and managing environmental pressures on marine and terrestrial ecosystems.

In addition, such a strategy should ensure that research infrastructure, the research workforce and collaborative relationships are developed in a balanced and structured manner, giving Australia the comprehensive basic and applied research capability it needs to meet current and future challenges.

NATIONAL RESEARCH INVESTMENT PLAN: OBJECTIVE

The objective of the National Research Investment Plan is to guide and coordinate Australian Government investment in research. It seeks to do this in a way that:

- improves the living standards and wellbeing of Australians through the building of a national research fabric that
  - contributes to increased productivity in the public and private sectors; and
  - addresses national and global challenges.

NATIONAL RESEARCH INVESTMENT PLAN: PRINCIPLES

The rationale for Australian Government investment in research and innovation, reflected in the objective set out above, points to the investment principles needed for the National Research Investment Plan to be effective. These principles include attention to the conduct of excellent research that increases productivity and addresses national challenges.

The investment principles also provide guidance on the way that Australian Government investment should be delivered. This guidance is consistent with principles that have previously been developed for the treatment of particular elements of research and innovation. For example, the government's Research Workforce Strategy identifies seven aspirations that underpin its vision for development of the Australian research workforce (Appendix G).[107] In essence, these aspirations revolve around providing the quantity and quality of research skills needed to drive productivity improvements across the economy.

The *Strategic Framework for Research Infrastructure Investment* (Appendix H) sets out nine principles for research infrastructure investment, many of which are relevant to research investment in general. The infrastructure investment principles

107 DIISR (2011b), *Research Skills for an Innovative Future – A Research Workforce Strategy to Cover the Decade to 2020 and Beyond*

include directing investment to priority needs, pursuing excellence and encouraging collaboration. In addition, they emphasise the need for continuity of program funding and the importance of funding all relevant cost components:

> Research infrastructure funding programs should be ongoing and predictable, to achieve optimal use of funds.
>
> The ability to invest in human capital and operating costs results in superior service delivery and more efficient, productive and viable research infrastructure facilities.[108]

In some situations, government investment will be required for a finite period to address a particular research question or to fill a particular need for research capacity. However, those programs that are core to sustaining Australia's research fabric need to be ongoing, as stop-start funding for core activities imposes additional costs and makes the government's investment less effective.

The Productivity Commission[109] and the research infrastructure investment principles both highlight the need for transparent evaluation and reporting arrangements. This principle applies not just to terminating programs, but to ongoing programs which should also be subject to periodic review.

Installing shields to prevent radio frequency interference from affecting the signals collected by CSIRO's ASKAP antennas (Courtesy of the CSIRO, credit Russ Bolton)

108 DIISR (2011f), *Strategic Framework for Research Infrastructure Investment*

109 Productivity Commission (2007), *Public Support for Science and Innovation*, Research Report, 9 March

ACTION 2:

The Australian Government has adopted the following principles for research investment.

1. Enhance productivity growth
Investment in research and innovation should result in the adoption of improved products and processes by end-users from both the business and non-business sectors.

2. Address Australia's key national challenges
Investment in research and innovation should address Australia's key economic, social and environmental challenges so as to improve the wellbeing of Australians.

3. Increase the stock of knowledge
Investment should support the discovery of knowledge that current and future generations can utilise in innovative ways.

4. Support global quality and scale
Investment should support the quality and scale of Australian research and innovation capability needed to collaborate effectively with world-leading researchers and businesses.

5. Deliver a strong, cohesive research fabric
Investment should:

- result in the quality and quantity of researchers needed by the business and academic communities;
- provide high quality research infrastructure;
- facilitate enduring collaborative relationships between researchers and end-users from both the business and non-business sectors;
- develop enabling capability in the five key domains;
- support a balance of mission-led and investigator-led research;
- support basic and applied research across a broad range of disciplines; and
- employ a mix of strategic, competitive, formula-driven and entitlement funding mechanisms.

6. Create a sustainable capability
Investment should be made with a view to sustaining the long term viability of Australia's research and innovation capability. Funding for core research and innovation programs should be ongoing and predictable.

7. Be subject to monitoring and evaluation
Investment should be subject to regular, rigorous and transparent monitoring and evaluation to assess efficiency and impact. The value of the National Research Investment Plan as an investment planning process should also be subject to periodic evaluation.

7. ENABLING CAPABILITY

Enabling capability is required in five key domains that have been identified as underpinning vital areas of public and private sector research. The domains bring together the fundamental elements of workforce, infrastructure and collaboration to create capability that can be applied to a range of research endeavours.

The domains are not discipline-specific. They are inherently multidisciplinary in nature, providing an environment in which researchers can come together to enable research across multiple applications. The domains allow for a range of organisations including end-users to access and share expertise and resources to address complex and interrelated issues.

The domains are highly interdependent in the way they enable individual fields of research. Cancer research, for example, might be supported by all five domains:

- Physical domain: data on atmospheric pollutants;
- Natural domain: gene sequencing facilities, biobanks of tissue samples, bioinformaticians;
- Human domain: epidemiologists, data on smoking rates, social analysis of risk factors;
- Technology domain: microscopy and imaging facilities; and
- Information domain: eResearch infrastructure, access to the outcomes of earlier research and supporting data.

The virtue of developing underpinning capability across the domains is that any researcher is then able to draw upon all of the expertise and resources required to conduct high quality research into their particular research question. A unifying thread across all the domains is the importance of data. Australia's key research challenges will be increasingly data intensive and data driven.

The brief summaries of the domains provided below have been derived from consultation with stakeholders including business, universities, Commonwealth, State and Territory governments and private non-profit research institutes. They also build on the capability requirements outlined in the *2011 Strategic Roadmap for Australian Research Infrastructure*, which was itself developed through a consultative process.

PHYSICAL DOMAIN

The Physical domain underpins research in areas such as marine, terrestrial, geological, atmospheric, climate, coastal, freshwater and resources. It supports research on issues such as land use, water, energy, natural disasters, climate adaptation, resource deposits and sustainably managing our environment.

The domain includes expertise and facilities that collect and utilise integrated observations spanning global to regional scale and employing satellite, ocean, and land-based systems. The resulting large data sets will be brought together to support integrated analysis and modelling that increases our understanding of the earth and its systems.

NATURAL DOMAIN

The Natural domain underpins research of living systems, in areas such as agriculture, health, medicine, biodiversity and biosecurity. It includes the workforce, facilities, and collaboration needed to support biological discovery and integrated life sciences research.

The domain includes the creation, access and use of large data sets holding many different types of biological information, as well as support for data linkage and bioinformatics, biostatistics and computational biology. Creation of capability based on large scale data will allow Australia to establish strong relationships with leading biological research organisations around the world, thereby enabling Australia to access and utilise the best biological data and expertise no matter where it is located.

HUMAN DOMAIN

The Human domain underpins research in areas such as education, law, society, economics, demographics, history, Indigenous studies, culture, language, the creative arts, high performance sports, and health and wellbeing. It supports understanding of the human dimensions of complex societal systems such as resource consumption, energy use, waste production, urban space usage, housing, transport and ICT usage. These aspects vary spatially and require analysis from national, metropolitan and regional perspectives.

The domain includes the capability to make old and new data discoverable and reusable and to extract greater value from existing collections that are as varied as statistical data, manuscripts, documents, artefacts and audiovisual recordings. This domain will enable discovery and use of previously inaccessible information, stimulating connections and synergies and catalysing innovative research.

TECHNOLOGY DOMAIN

The Technology domain underpins the development of cutting edge technology across a range of areas including nanotechnology, biotechnology, ICT, space and astronomy. These technologies have widespread applications in areas such as manufacturing, health, transport, communications, engineering and energy, both for public good and for major commercial opportunities across a range of industries.

The domain supports the development of new processes, techniques and instruments, including disruptive technologies that have the potential to revolutionise our way of doing things. It also includes the underpinning areas required to analyse the structure, chemistry and physical properties of materials and to synthesise advanced materials, fabricate device components and produce prototypes.

INFORMATION DOMAIN

The Information Domain underpins all fields of research. It includes the ICT workforce, platforms, data environment, computational techniques and support structures that enable researchers to explore new fields of research and to accelerate research outcomes in new and novel ways. It provides the means to manipulate, manage, share, integrate, link and reuse research data and enables new insights through simulation, modelling and analysis.

This domain assists researchers and research teams to share resources, work together more effectively and gain access to results, instruments, data and analysis capabilities located anywhere in the world. It is also supported by policies encouraging open access to the results of publicly funded research.

DOMAIN PLANNING

Australian Government leadership is necessary to coordinate investment within and across the domains, thereby building the national capability needed to increase productivity and address Australia's key challenges. In order to guide future investment, further work is needed to specify the current capability of the domains and to identify action required to address gaps and vulnerabilities. The domains are highly interrelated and the greatest impact will be achieved if they are conceived and developed in parallel, as parts of a complementary whole.

The assessment of current and future enabling capability in the domains will include consideration of:

- Australia's areas of research and innovation strength;
- opportunities to build strategically important research capability;
- workforce or skill gaps that impact on Australia's capability in the five key domains;
- infrastructure needs, including action required to maintain the currency of research infrastructure and to enable capacity to keep pace with demand; and
- opportunities to build collaborative relationships nationally and with major international initiatives and organisations.

ACTION 3:

ARCom will prepare a detailed plan to develop enabling capability across the five key domains. The plan will:

- identify demand by business, higher education, government and the private non-profit sector;
- identify present research capacity and capability across the domains;
- recommend action to address any identified gaps and vulnerabilities; and
- ensure that end-users from business and government are involved in the development of the plan and have access to the resulting research capability and research outputs.

8. FUNDAMENTAL ELEMENTS

A strong, sustainable research fabric requires ongoing investment by government in the five fundamental elements shown in Figure 5.1 Australia's Research Fabric. Each of these elements is essential to the conduct of research and the absence of any one component will severely reduce the effectiveness of the government's investment as a whole.

Government funding for programs that are core to sustaining the fundamental elements should avoid stop-start arrangements that impose additional costs and work against strategic development of Australia's research capacity. Such programs should be funded on an ongoing basis, while other programs that address needs with a finite time horizon should terminate when no longer required. Whether each program is ongoing or terminating should be communicated clearly to stakeholders in the research sector.

ACTION 4:

Australian Government research and innovation programs will provide ongoing support for each of the fundamental elements of the research fabric: publicly funded research, the research workforce, research infrastructure, domestic and international collaboration and business research.

Each research funding program proposal presented for consideration by the Australian Government should be consistent with the investment principles set out in Section 6, and should demonstrate that the research fabric will be able to provide the quality and quantity of each fundamental element needed to deliver the desired outcome.

ACTION 5:

Proposals for additional Australian Government science and research funding programs (or substantial changes to programs) should use the framework and principles outlined in the Plan to guide decision making and to ensure the proposal can be successfully implemented.

PUBLICLY FUNDED RESEARCH

ACTION 6:

- To provide the multidisciplinary capacity required to respond flexibly to evolving challenges, the Australian Government will continue to support a wide range of high quality basic and applied research.
- To increase the efficiency of grant allocation processes, and better support excellent Australian researchers, the ARC and NHMRC will be asked to consider options for the more widespread use of research grants of longer duration directed to individuals and teams.
- To capture the full value of the Australian Government's research investment, ARCom will provide advice on a whole-of-government approach for opening access to the outputs and data from publicly funded research.

GOVERNMENT SUPPORT FOR RESEARCH

Publicly funded research includes basic and applied research conducted in universities, government research agencies and non-profit research organisations. Australian Government support for university research occurs primarily through formula based funding such as the Sustainable Research Excellence in Universities Program and through ARC and NHMRC grants for university researchers.

The government should continue to support high quality, mission-based and investigator-led research across the full range of disciplines. This breadth of research expertise will be essential in providing the multidisciplinary capacity needed to tackle complex research questions.

In particular, the government needs to sustain support for basic research and other research of a public good nature. Figure 8.1 shows that, while expenditure on basic research has increased over the 15 years to 2008-09, the proportion of Australia's research effort directed to basic research has decreased from almost 30 per cent to around 20 per cent.

In 2008-09, the higher education sector accounted for almost 60 per cent of basic research conducted in Australia. However, Figure 8.2 shows that the proportion of higher education expenditure directed to basic research has declined markedly over the past 20 years. Given the importance of basic research as a source of knowledge creation that all sectors draw upon to innovate and increase productivity, Australia needs to ensure that it has a sustainable basic research capability.

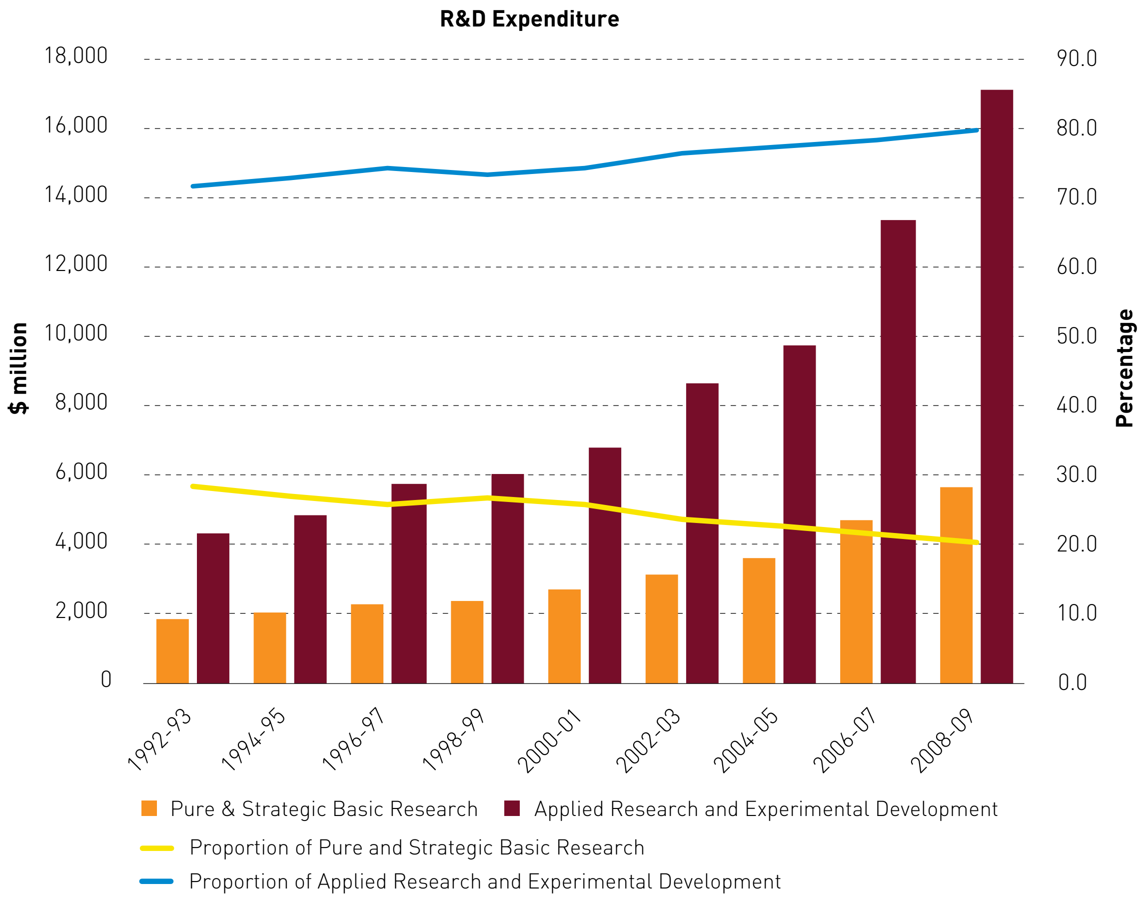
Australian Government research agencies, working with other researchers, business and end-users, play an important role in progressing public good research. In real terms, funding increases for the government's research agencies have been small or non-existent since 2002-03.[110] Future increases in funding for these agencies should be consistent with the investment framework set out in this Plan.

RESEARCH GRANTS

With regard to ARC and NHMRC research grants, the review of publicly funded research found there was general support for continuation of rigorous peer review of competitive grant programs that fund individual research projects.[111] However, it noted that ARC applicants experience a success rate of only around 20 per cent.

Figure 8.1: GERD by type of activity, 1992-93 to 2008-09

Source: Research and Experimental Development, All Sector Summary, Australia. ABS cat. no. 8112.0 – Various Issues

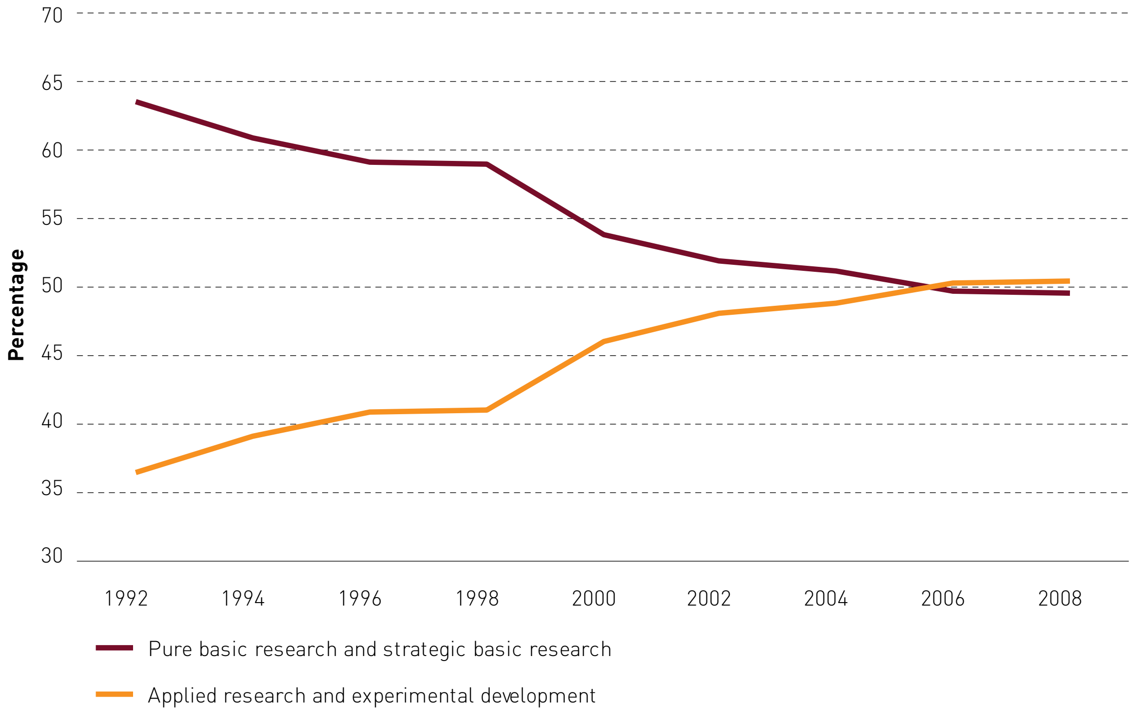


110 Office of the Chief Scientist (2012a), *Health of Australian Science*, May

111 DIISR (2011a), *Focusing Australia's Publicly Funded Research Review – Maximising the Innovation Dividend*, Review Taskforce, Research Division, Canberra

Figure 8.2: Proportion of Higher Education Expenditure Directed to Basic and Applied Research

Source: ABS Research and Experimental Development, All Sector Summary, Australia, 2008-09 (2010)



Given the substantial resource cost incurred both by researchers and the government in dealing with unsuccessful applications, it would be desirable to examine ways of increasing the overall efficiency of grant allocation processes. In this context, a shift toward more widespread use of grants of longer duration, directed to individuals and teams, would be beneficial as it would also enable more of Australia's excellent researchers to build strong research teams and focus their effort on longer term programs of research.

In the case of the NHMRC, consideration of revised grant allocation processes would need to take account of, and be consistent with, the outcomes from the Strategic Review of Health and Medical Research.

OPEN ACCESS

In principle, the results of publicly funded research should be widely available so that the maximum benefit can be gained from the knowledge created.

As a result, other countries are increasingly adopting open access publishing and open science policies. For example: such policies already operate in the US, the UK Government has decided to establish an open access model and the European Commission has announced that open access policies will be fundamental to the new European Union research funding program.

Open access is the principal feature of the practice of open science and refers to the making of research findings openly and freely available, via the web. Open access publishing involves making published research outputs such as journal articles (including underlying data where appropriate) available to a wide audience through the internet, usually by placing an electronic copy of the publication in an online institutional repository. Open data, which is sometimes included as an aspect of open access, refers to the application of similar principles to scientific research data. Open access publishing of the outputs of publicly-funded research, including published findings and research data sets and databases, has the potential to increase knowledge transfer to a wide range of research users.

In Australia, the NHMRC has adopted a mandatory open access policy on dissemination of research findings, requiring that any publications arising from an NHMRC supported research project must be deposited in an online institutional repository within a 12-month period from the date of publication. This policy came into effect on 1 July 2012 and brings the NHMRC in line with other international health and medical research funding bodies, such as the National Institute of Health in the United States, the Wellcome Trust and the UK Medical Research Council.

The ARC is reviewing its open access policy to bring it in line with that operated by the NHMRC. Presently, the ARC does not mandate that its grant recipients publish their research outputs in open access journals or make their research outputs available in open access repositories. However, the ARC strongly encourages the publication of the research that it funds in publicly accessible outlets, and has done so through its Funding Rules since 2007.

It would be desirable to examine a whole-of-government approach on open access to publicly funded research so as to capture the full benefit of the government's research investment.

RESEARCH WORKFORCE DEVELOPMENT

ACTION 7:

Building on work being progressed under the Research Workforce Strategy: *Research Skills for an Innovative future*, ARCom will:

- propose measures to help ensure the future supply of research skills can meet demand;
- examine the structural issues associated with research careers in higher education and propose measures to make these careers more attractive, including by increasing the flexibility for early to mid-career researchers to gain experience in other roles and/or sectors; and
- propose measures to provide research students with the generic skills and innovation capabilities needed to be productive in a wide range of employment contexts, including business.

The Australian Government's 2011 Research Workforce Strategy identified the following areas as deserving priority attention:

- meeting demand for research skills;
- increasing participation in Australia's research workforce;
- enhancing the attractiveness of research careers in Australia;
- facilitating research workforce mobility; and
- strengthening the quality of supply through Australia's research training system.

These issues will require continued policy action if Australia is to have a robust national research fabric over the coming decade.

MEETING THE DEMAND FOR RESEARCHERS

Growth in demand by business, academia and government for people employed with doctorate by research qualifications is projected to grow at 3.2 per cent annum over the period to 2020. This growth will be much faster than growth in total employment which is projected to grow at 1.5 per cent annum.[112] Despite this projected increase in demand for research qualified workers, Australia's production of domestic higher degree qualified staff has stalled; rising less than 1 per cent between 2006 and 2011 (see Figure 8.3). As a result, Australia will need to rely on migration and retaining international students in order to meet the demand for research qualified staff.

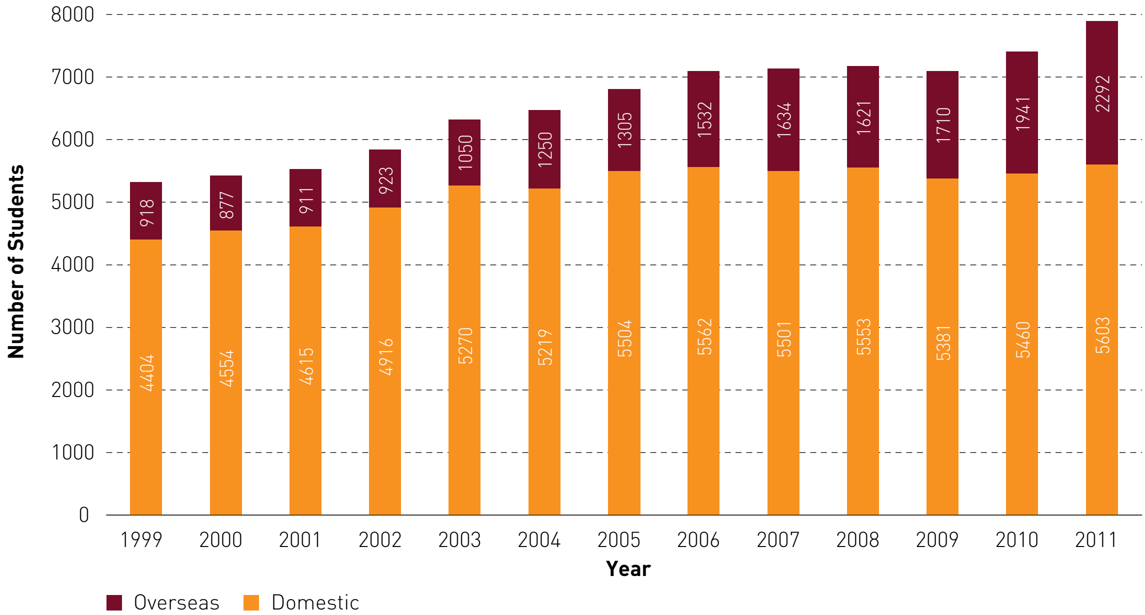
In fact, it has been estimated that, under an 'innovation scenario' where Australia increases national R&D expenditure to 2.5 per cent of GDP by 2020, demand for research skills will exceed supply for almost all of the coming decade.[113]

112 Access Economics (2010), *Australia's future research workforce: supply, demand and influence factors*, a report for the Department of Innovation, Industry, Science and Research, April

113 Access Economics (2010), *Australia's future research workforce: supply, demand and influence factors*, a report for the Department of Innovation, Industry, Science and Research, April

Figure 8.3: Number of Students Completing Higher Degrees by Research in Australia (1999-2011)

Source: DIISRTE analysis of Higher Education Information Management System (HEIMS) - unpublished data



Serious research skill shortages are evident at the level of specific disciplines and fields of research. Domestic undergraduate enrolments for students beginning in information technology halved between 2002 and 2010, while enrolments in agriculture and environment decreased 4 per cent. The enabling sciences of mathematics, chemistry and physics all suffered declines in enrolments among undergraduate science students in the 1990s, especially beyond their first year of study. These losses were not recovered in the subsequent decade, with these disciplines remaining at their late-1990s lows.[114]

The reduced supply of skills in these disciplines does not sit well with the expected demand for skills. Consultation with stakeholders has already identified concern about shortages in areas such as the core science disciplines, informatics, statistics and computational science.

Declining enrolment in higher degrees by research is also an issue for other disciplines such as education, history and archaeology.[115] In addition, there is strong demand for technicians and research support staff who are often highly skilled and possess specialist expertise that is essential to the conduct of quality research. These staff represent 33 per cent of the research workforce.[116]

114 Office of the Chief Scientist (2012a), *Health of Australian Science*, May

115 DIISR (2010b), *Research Workforce Strategy: Discipline Case Studies*

116 ABS (2010a), *8112.0 Research and Experimental Development, All Sector Summary, 2008-09*

The Australian Government provides support for the training of researchers via the Research Training Scheme and Australian Postgraduate Awards. However, individual students choose their area of study based on a complex mix of personal interest, perceived relevance, career pathways, expected remuneration and other factors. Innovative measures are likely to be needed for Australia to overcome future research workforce shortages and meet the demand by business, higher education and government.

PARTICIPATION, CAREERS AND MOBILITY

The fall in supply of science and research skills starts with the school system, where between 1992 (after which school retention rates were fairly stable) and 2009, the proportion of Year 12 students taking physics, chemistry and biology fell 31 per cent, 23 per cent and 32 per cent respectively.[117]

In September 2012, Prime Minister Gillard set a goal of lifting Australia into the top five schooling systems in the world by 2025.[118] Currently, Australia is ranked 7th on reading and science and 13th on mathematics. This policy goal is supported by, among other things, the Australian Government's earlier announcement of $54 million to provide more science and mathematics teachers equipped with better training and better resources.[119] This initiative responded to a report by the Chief Scientist that highlighted the need to make the teaching of science more interesting and relevant to students including by bringing the active practitioners of mathematics, engineering and science into the classroom to share their expertise and enthusiasm. As the Chief Scientist's report noted:

> The issue is that science is not taught as it is actually practised: hypothesis, experimentation, observation, interpretation and debate. And interesting ways of getting the facts into context are not used often enough.[120]

The combination of the government's school-level science initiative and development of enabling capability in the five key domains that underpin Australia's research fabric provides an opportunity to build practical bridges between school-age students and the research community. For example, students could contribute to the collection of terrestrial, marine, atmospheric and biodiversity data for inclusion in enabling capability databases, and as part of specific research projects. In this way, students would not only learn about, but also participate in, the process of research and discovery. Such an initiative would increase student interest in science and research careers and would, over time, lead to the community as a whole becoming increasingly science literate.

A further factor that limits the number of people undertaking higher degrees by research is the nature of a research career itself. Defined research pathways do exist in government research organisations and in business, however the situation is much less clear in higher education. An early career researcher at a university faces a casualisation of their employment, tied to the duration of individual projects

117 Office of the Chief Scientist (2012b), *Mathematics, Engineering and Science in the National Interest*, May

118 Prime Minister the Hon Julia Gillard MP (2012), *A National Plan for School Improvement*, speech to the National Press Club, Canberra, 3 September

119 Senator the Hon Chris Evans (2012), *Investing in science and maths for a smarter future*, Media Release, 8 May

120 Office of the Chief Scientist (2012b), *Mathematics, Engineering and Science in the National Interest*, May

and research grants. The decline in tenured positions or alternative employment arrangements means that academics are increasingly finding themselves stuck on the post-doc treadmill.[121]

In addition, early career and mid-level researchers in universities are likely to be involved in teaching and other activities as well as research. As a result, university researchers at these levels are estimated to spend 40 per cent of their time on research, whereas similar researchers in business, government or other research centres spend 80 per cent of their time on research.[122] Furthermore, funding for the Australian Government's Future Fellowship scheme will cease in 2014 which will create a gap in support for excellent mid-career researchers.

Research careers in higher education are not only fragmented and ad hoc in their early years, but also subject to career bottlenecks at formative stages such as the transition from student to independent researcher and from research to leadership roles.[123] Furthermore, the need to maintain a record of research publication does not allow researchers the flexibility to gain part-time and/or temporary experience in industry, clinical environments, infrastructure management or government.

RESEARCH TRAINING

Apart from issues that stem from shortage of supply, the discipline-specific skills of Australian PhD graduates are generally considered to be high.[124] However, employers in both the private and public sectors have identified a need for research graduates to have improved 'soft' skills such as communication, teamwork, project management and commercialisation. The requirement can be described in this way:

> A 'T skills' approach may be applicable to describe the combination of skills a researcher requires for the future – deep, narrow and discipline focused skills and broad soft or life skills.[125]

The Australian Government has recognised this issue and provided seed funding to the Australian Technology Network of universities to establish Australia's first industry-collaborative doctoral training centre designed to provide research students with the leadership, communication and management skills needed for them to bridge academic, scientific and industrial boundaries. Increased industry input into the structure, quality and accreditation of courses has the potential to better match the capabilities of research graduates with the needs of industry. It is likely that providing a variety of PhD delivery models including, for example, the option of placements in industry and/or formal communication skills training, will generate a mix of researchers with different emphases in their training that prepare them for different roles in business, academia or government.

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121 Coates H et al (2009), *The attractiveness of the Australian academic profession: A comparative analysis*, Changing Academic Profession Research Briefing, October

122 Allen Consulting Group (2010), *Employer Demand for Researchers in Australia*, Report to the Department of Innovation, Industry, Science and Research, March

123 DIISR (2011b), *Research Skills for an Innovative Future – A Research Workforce Strategy to Cover the Decade to 2020 and Beyond*

124 DIISR (2010b), *Research Workforce Strategy: Discipline Case Studies*

125 Allen Consulting Group (2010), *Employer Demand for Researchers in Australia*, Report to the Department of Innovation, Industry, Science and Research, March

RESEARCH INFRASTRUCTURE

ACTION 8:

- The Australian Government will consider mechanisms to provide ongoing support for major national research infrastructure as current programs are coming to an end. These mechanisms should be consistent with the principles set out in the *Strategic Framework for Research Infrastructure Investment.*
- The Australian Government will evaluate landmark research infrastructure proposals in the context of this Plan on a case by case basis, taking into account advice provided by ARCom.

Over the coming decade, the role of infrastructure will be central to the conduct of excellent research. The systematic collection of observations, the management of the resulting data sets, the tools to analyse the data and the connection of the collaborating researchers will all require the most up to date research infrastructure.

The collection of information will be highly structured and will be stored in organised data sets so as to facilitate access to the information and its re-use by multiple researchers in multiple applications. Information management as a capability will require not just the provision of eResearch infrastructure, but also the setting of a supportive policy environment, access to relevant skills and effective domestic and international collaboration. These elements are brought together in the Information domain described in Section 7.

The functionality of Australia's research infrastructure will be heavily dependent on the software and applications that enable researchers to optimise their use of the research instruments and systems. As a result, the infrastructure will require constant enhancement of its applications and software, and periodic upgrading of its hardware, to avoid becoming obsolete. Given the complexity of the instruments and systems, and the constant and rapid evolution of their capability, the infrastructure will need to be operated by dedicated, highly skilled staff who are able to manage the infrastructure and guide researchers in use of the equipment.

Research infrastructure is also evolving into global networks that underpin multidisciplinary research. The increasing complexity and cost of construction and operation of major research infrastructure, will continue to be more than a single nation can manage. Australia's success in developing collaborative networks of national research infrastructure through NCRIS places it well to collaborate and integrate with international ventures. The ability to share research infrastructure development and to access international facilities will be critical. Australian facilities are building international links now, notably with European and North American partners. These linkages will bring great benefit to Australian and international researchers, increasing the flow of expertise and ideas which drives innovation.

NATIONAL RESEARCH INFRASTRUCTURE

Experience with NCRIS and the Super Science Initiative has shown that a collaborative model provides the best value for money when investing in national research infrastructure. Such a model:

- uses a strategic approach to direct funding to priority investments;
- avoids unnecessary duplication of facilities;
- enables researchers to access the most modern facilities on the basis of merit;
- achieves high levels of utilisation;
- provides a flexible facility that can adjust to meet changing needs and can respond to calls for urgent research on specific threats, for example influenza pandemics;
- provides funds for skilled staff to manage and operate the infrastructure;
- encourages increased collaboration among Australian researchers, including business researchers; and
- provides facilities that attract increased collaboration and support from international researchers and investors.

The investment principles that bring about these outcomes are set out in the *Strategic Framework for Research Infrastructure Investment* (Appendix H).[126] Key among these principles is the need for infrastructure funding to be holistic – supporting all capital, maintenance and operating costs associated with the infrastructure. The desirability of this approach has been recognised since the National Research Infrastructure Taskforce[127] reported in 2004, with its effectiveness confirmed by the 2010 NCRIS evaluation[128] and reaffirmed by the *2011 Strategic Roadmap for Australian Research Infrastructure.*

The 2008 Review of the National Innovation System (*Venturous Australia*) recommended funding a successor program to NCRIS at the level of $150 to $200 million per annum.[129] However, funding for the NCRIS program ($542 million over seven years) ended on 30 June 2011 and Super Science funding ($901 million over five years) ends on 30 June 2013 with no subsequent national research infrastructure program having been established.

In recent years, Australia has put in place a range of world-class research facilities including the Integrated Marine Observing System, Atlas of Living Australia and Australian Plant Phenomics Facility. With all national infrastructure funding coming to an end, these and other excellent research facilities will lose essential staff to overseas operators and the equipment available to Australian researchers will soon become obsolete.

Box 8.1 provides an example of a cost-effective, NCRIS-funded infrastructure initiative that brings together researchers in business, government and higher education to increase national wellbeing.

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126 DIISR (2011f), *Strategic Framework for Research Infrastructure Investment*

127 DEST (2004), *Final Report of the National Research Infrastructure Taskforce*

128 DIISR (2010a), National Collaborative Research Infrastructure Strategy Evaluation Report, June

129 Panel to Review the National Innovation System (2008), *Venturous Australia – Building Strength in Innovation*

BOX 8.1: RESEARCH INFRASTRUCTURE IMPROVES NATIONAL WELLBEING

The Australian National Fabrication Facility (ANFF) was established under the NCRIS program. Australian Government investment of $91 million has been highly leveraged, with the project's value approaching $200 million. The ANFF provides cutting-edge equipment and expertise in nano and micro fabrication. The ANFF Board has an independent Chair and 5 industry-based Directors from ResMed, Bionomics, Invetech, Silanna and G James Glass. Global nanotechnology industries are predicted to achieve a $3 trillion market with six million workers by 2020.[130]

ENHANCING AUSTRALIA'S RESEARCH CAPABILITY

The ANFF links 19 universities and CSIRO to form a portfolio of almost 500 tools spread across eight nodes that enables users to process hard materials (such as metals, semiconductors and ceramics) and soft materials, and to transform these into structures that have applications in sensors, medical devices, nanophotonics and nanoelectronics. The cohort of 60 highly skilled technical staff provides a world-class operating environment that is available to researchers across Australia.

Facility usage exceeded 61,000 hours for the 2011-12 financial year: with services direct to industry accounting for 12 per cent of facility time and non-business users exceeding 1400. Outcomes included fundamental research published in high-impact journals (272 publications in 2011), collaborative research with industries including automotive, food, and defence, and translational research such as development of the Nanopatch™.

ANFF infrastructure is underpinning collaboration with the US on the theme of Smart Sensors. A May 2012 scoping meeting in Washington was attended by 30 Australian delegates and US representatives from, among others, the Army, Air Force, Navy, NASA, National Science Foundation and the National Institute for Health.

INCREASING PRODUCTIVITY

The ANFF works closely with a wide range of businesses, assisting them to develop improved products for market and enabling them to carry out better research at lower cost. For example, Phoenix Engineering Systems has three scientists working on a Nano-Particle Hydrophone Capability Technology Demonstrator project for the Defence Science and Technology Organisation. Phoenix had planned to construct an in-house laboratory but has instead embedded staff at the ANFF. This has enabled Phoenix to conduct the research far more rigorously and to broaden the scope to cover options that would not have been possible with a smaller in-house facility.

ADDRESSING NATIONAL CHALLENGES

The ANFF supports research that addresses a wide range of national challenges including health, energy and food production. Examples include: microfluidic sensors for rapid flu sensing diagnostics, water splitting for hydrogen fuel cells, the ultrasonic production of skim milk and a project to improve the efficiency of mussel farming.

130 Roco et al (2010), *Nanotechnology Research Directions for Societal Needs in 2020*, Springer, Berlin and Boston, September

For Australia's research fabric to remain sustainable it requires funding for national research infrastructure. It is not possible to manage large research facilities with any continuity or efficiency, or to retain specialist expertise that is in high demand around the globe, when the existence of infrastructure funding programs is uncertain, or ceases altogether.

In the first instance, a new national, collaborative infrastructure program should address the needs identified in the *2011 Strategic Roadmap for Australian Research Infrastructure.* The Roadmap already reflects many national infrastructure requirements relating to the five key domains, for example, the development of major biological data sets, the creation of virtual workspaces for human systems research, the provision of marine, terrestrial and atmospheric observing systems, enhancement of the OPAL reactor and further development of eResearch infrastructure. However, a new national infrastructure program will also need to take into account any further national infrastructure requirements that emerge from the Plan developed for the five domains.

Decisions relating to the location, operating and governance arrangements for national infrastructure should include consideration around critical mass, as well as research concentration and collaboration.

OTHER INFRASTRUCTURE NEEDS

In addition to facilities of national significance, the *Strategic Framework for Research Infrastructure Investment* identifies the need for *local* and *landmark* investments.

Local investments are those infrastructure investments relating to a single institution or project and usually owned and operated within one institution. Such infrastructure is generally funded through a research organisation's own resources or via programs such as university block grants or the ARC's Linkage Infrastructure, Equipment and Facilities (LIEF) scheme.

Landmark investments relate to large-scale facilities that are often regarded as part of the global research capacity and that engage national and international collaborators in investment and access protocols. Examples of landmark investments include the Square Kilometre Array (SKA), ANSTO's OPAL reactor and the Antarctic research and re-supply ship the *Aurora Australis*.

Landmark infrastructure investments generally involve long lead times and have complex, cross-portfolio implications. Funding decisions for such projects are often staged and reviewed over a considerable number of years as circumstances evolve. Such proposals require detailed technical and financial evaluation from a whole-of-government perspective. ARCom's role and membership make it an appropriate body to provide such advice to government in the context of this Plan.

DOMESTIC AND INTERNATIONAL COLLABORATION

ACTION 9:

- ARCom will provide ongoing advice on improving linkages and collaboration between the research sector and industry.
- ARCom will provide advice on mechanisms to support strategic international research collaboration that would not take place without government facilitation and support.

DOMESTIC COLLABORATION

Australian Government support for collaboration is primarily provided through programs such as:

- the Cooperative Research Centres program;
- Rural Research and Development Corporations;
- CSIRO's National Research Flagships;
- ARC and NHMRC linkage schemes, including centres of excellence;
- Joint Research Engagement program; and
- the Collaborative Research Networks program.

The Super Science Initiative and NCRIS support collaboration through investing in research infrastructure in a manner that fosters strong, enduring relationships among researchers and end-users, both domestically and internationally.

Collaboration in research has multiple dimensions. It can involve linkages across research disciplines, fields of research, institutions, research sectors including business, and across countries. Given the global, non-linear nature of modern research, it is often necessary for research teams to establish all of these linkages plus relationships with potential end-users of the research.

There is a need to extend current programs that promote and support linkage and collaboration between public and private sector organisations to place greater emphasis on building critical mass (both physical presence and virtually connected capabilities) around areas of local research capability, regional comparative advantage and demonstrated market opportunity. A key objective should be to ensure that Australian researchers and end-users are well connected to national and global networks.

One mechanism that can achieve this objective is to develop innovation precincts with national and global focus and commitment and a whole-of-value chain approach. While some clusters and hubs embodying this concept already exist, they are relatively small in scale and do not possess or have access to the full suite of industrial expertise, research capabilities and resources needed to attract global investment and support participating firms in penetrating global supply chains or capturing major new market opportunities.

Adoption of the research fabric as a planning framework requires that all facets of collaboration be considered whenever a research initiative is implemented. The development of enabling capability in the five domains provides a particular opportunity to draw together, and engage, expertise and resources across all sectors, including through the interchange of researchers between organisations and research sectors.

ARCom will consolidate experience gained in building collaboration within the domains for use in framing future updates to this Plan. ARCom will also consult with the DIISRTE Portfolio Roundtable on Research-Industry Linkages, which includes representatives from CSIRO, ANSTO, AIMS and the ARC. The Roundtable aims to better understand how industry collaboration occurs and to articulate the policy opportunities and constraints regarding increased industry collaboration with other research sectors.

INTERNATIONAL COLLABORATION

Some 97 per cent of knowledge creation occurs outside Australia. It is imperative that Australia is able to harness this global research capability and apply it to the creation of local benefit. International research collaboration can provide substantial leverage of Australia's domestic research investment by providing access to knowledge, expertise and infrastructure that is not available in this country,[131] and can greatly increase the citation impact of Australian research. It also assists in the delivery of broader Australian Government objectives in aid, trade and diplomacy.

As was demonstrated in Section 3, the extent of international collaboration by Australian researchers has grown rapidly over the past 10 years. The vast majority of this collaboration is initiated and funded by individual researchers and research organisations in the normal course of their work.

In some cases, however, strategically important research collaboration does not take place without government support. Examples of this sort include:

- where the partner country requires a government-to-government agreement be put in place as a basis for the engagement, for example China;
- where an international initiative requires national level participation, for example the Square Kilometre Array and the European Molecular Biology Laboratory; and
- where an emerging research nation is of strategic significance but Australian researchers and institutions lack established relationships, for example India and South Korea.

The Australian Government has programs in place to support development cooperation (the Australian Centre for International Agricultural Research) as well as research collaboration with China (funding available until 2013-14) and with India (funding available until 2015-16). However, there is currently no overarching government mechanism to support strategic research collaboration opportunities with the rest of the world.

131 DIISR (2011e), *Evaluation of the International Science Linkages Program.*

Current arrangements limit Australia's ability to partner with other countries and major international consortia. Stop-start funding mechanisms do not align with the expectations of partner governments and institutions, particularly in terms of timeframes and the need for certainty in future commitments. This can result in Australia missing out on the opportunity to be part of large-scale strategic international collaborations and to further leverage our investments in research.

Australia is also the beneficiary of international programs that support Australian researchers to work overseas, such as the Japan Society for the Promotion of Science (JSPS) Fellowships. If Australia does not have the capacity to reciprocate, key bilateral relationships may be undermined.

Forming new research partnerships takes time and effort, especially where the research and business cultures are unfamiliar or inaccessible in the absence of government facilitation. Mechanisms are needed that focus on building research relationships of significant national benefit that cannot be progressed without government-level participation. These relationships could include, as appropriate, formal government-to-government agreements, institutional partnerships, collaboration with business and end-users, researcher mobility programs and the creation of joint research centres. Support of this sort fills an important relationship building gap that cannot be progressed by individual institutions or met by one-off, project based research grants which often do not permit funds to be used for these kinds of activities.

Effective strategic relationship building results in strong, complementary linkages between individual researchers, research organisations and governments. Achieving deep, enduring international collaboration of this sort requires commitment by all sectors including government.

BUSINESS RESEARCH

ACTION 10:

Australian Government investment in enabling capability, and the fundamental elements of the national research fabric, should be more closely integrated with business research and the business sector's needs for innovation to support productivity growth.

Business research is largely of an applied nature, with some 94 per cent of business R&D involving experimental development and applied research. Key areas of business demand for research are in the fields of engineering and information and computing sciences, as well as medical and health sciences, technology (including biotechnology and nanotechnology), agricultural and veterinary sciences and built environment and design. The industry sectors most involved in research are manufacturing and mining, followed by the service sectors, construction, wholesale trade and information, media and telecommunications.[132]

The Australian Government's flagship program for encouraging business investment in research is the R&D Tax Incentive which provides support to the business sector of some $1.8 billion per year. The Tax Incentive is an entitlement-based, market driven program that supports eligible companies in all industry sectors.

In addition to receiving direct support for research, the business sector also benefits through access to research initiatives established with government investment. Examples include the CRC program and CSIRO Flagships which encourage business investment in research. Business can also choose to co-invest (or 'pay as you go') in national collaborative research infrastructure projects, thereby benefiting from cutting edge technology and expertise without having to finance and maintain expensive facilities of their own.

Australia can lift its business research outcomes through a continuing focus on firm level capabilities that promote and support innovation, in particular, management and design, alongside the technical knowledge and experience that supports firms to identify relevant knowledge and technology developments and to evaluate, adapt and apply them in the workplace.

Australia can also capture greater dividends from business investment in research through further focus on its translation into the market place. Australia currently loses many knowledge based start-ups to other countries because there is insufficient risk or venture capital in Australia. Existing government programs such as the Innovation Investment Funds and Venture Capital Limited Partnership schemes play a critical role in this regard, but there is a need for further effort to attract international investment into start-ups and to support their retention of skilled employees.

This Plan establishes a research investment framework that seeks to more closely integrate business and non-business research activity, including through the setting of strategic research priorities and an improved resource allocation focus which will, together, give direction to improved collaboration between business and research institutions. Closer links of this sort will provide publicly funded researchers with a better understanding of business research needs and with greater capacity to access, and work with, business research expertise.

132 See Figure 3.9 and Figure 3.10, which are based on ABS (2010a), *8112.0 Research and Experimental Development, All Sector Summary, 2008-09*

From a business perspective, the Plan aims to result in government investment in enabling capability, and each of the fundamental elements of the research fabric, being more closely aligned with business needs. Key aspects of the Plan that support business research include:

- business involvement in the development of enabling capability for the five key domains and access to the resulting research capability and research outputs;
- government support for basic research and the creation of a stock of new knowledge that can underpin business innovation;
- easier access by business to the outputs of publicly funded research;
- access to a supply of research qualified staff that meets the level of demand and skills required by business;
- access by business to national and landmark research infrastructure;
- government support for collaboration programs designed to strengthen links between the research sector and industry; and
- business participation in government-level collaboration initiatives with established and emerging research nations.

Researcher explaining the CSIRO developed TSG Core Software for mineral analysis (Courtesy of AuScope)

9. STRATEGIC RESEARCH PRIORITIES

ACTION 11:

- As the National Research Priorities are broad in nature and do not provide a focus for Australian Government research investment, ARCom will prepare a statement of more specific, strategic research priorities that reflects government needs for research and innovation to replace the National Research Priorities. This statement will provide a basis for targeting government investment in the research fabric and will be updated by ARCom every three years, or as required.
- ARCom will develop a process, for consideration by the Australian Government, that enables future research funding for departments and agencies to be more closely linked with the government's strategic research priorities.

Government represents a significant component of the demand for research: research that addresses challenges, improves productivity and provides a better evidence base for policy making. In this context, MIT has encouraged the US Government to build connections across stovepiped systems:

> ... our funding agencies, not just our scientists, should become collaborators. That means talking to one another, jointly identifying the areas of greatest opportunity as well as the top scientific challenges, and developing common strategies for progress.[133]

To date, this Plan has identified Australia's key challenges over the coming decade (as described in Box 5.1), and developed a research fabric that is framed to meet those challenges. The next step in ensuring government investment in the research fabric achieves maximum impact will be to focus effort more closely on the highest priority research needs relating to those key challenges.

The work conducted by DIISRTE in 2012 to refresh the National Research Priorities (NRPs) concluded that, while the NRPs provided a convenient summary of the scope of Australia's research endeavour, they were not an effective mechanism for targeting government research investment. As a result, further work will be required in the context of this investment planning process to identify more specific research priorities that relate to the key challenges already identified. These strategic research priorities can then form the focus of future government investment within the framework of the research fabric as a whole.

ARCom should therefore develop a statement of the Australian Government's strategic research priorities, and update that statement prior to the preparation of each Plan, or as required. This statement will need to build on the work undertaken to refresh the NRPs and any research priorities that have been identified, and that are being progressed, by individual portfolios.

133 MIT (2011), *The Third Revolution: The convergence of the Life Sciences, Physical Sciences and Engineering*, January

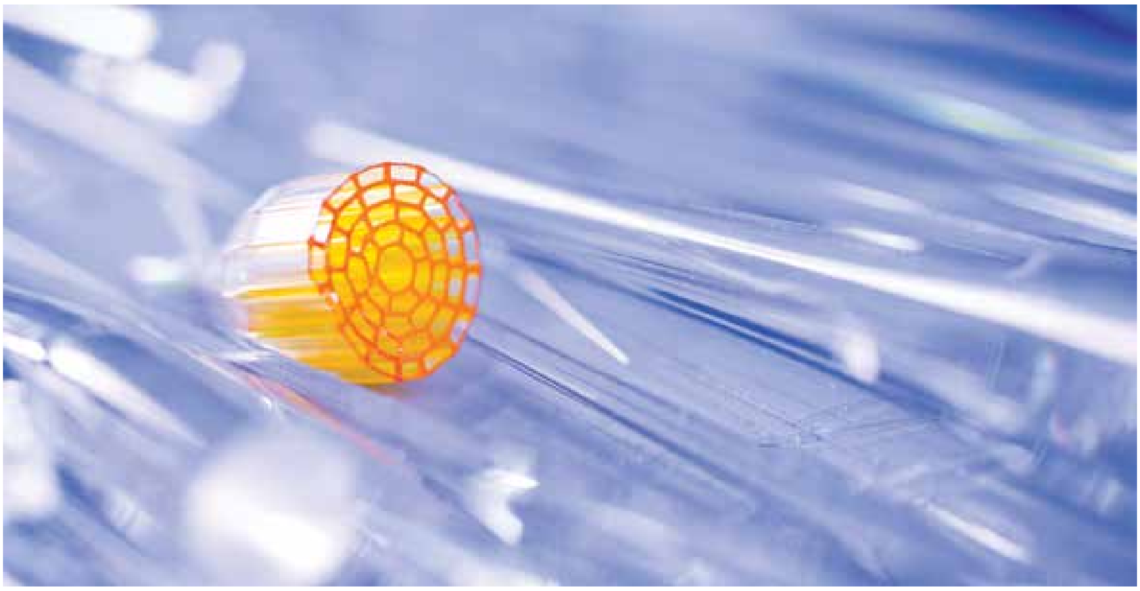
The government's research needs, as reflected in the strategic research priorities, should be taken into account when framing agency budgets and when considering individual investments in the research fabric.

ARCom should examine practice in other countries as background for developing a process that links the government's future statements of strategic research priorities with funding allocations. For example, the US Government links their budget process with a set of research priorities issued jointly by the Heads of the Office of Management and Budget and the Office of Science and Technology Policy.[134]

The process to develop priorities should involve consultation with industry, State and Territory governments and the broader research sector. Setting strategic research priorities will assist in harnessing the research effort and bringing it to bear on achieving improved national wellbeing and increased productivity. The priorities should be developed to encourage critical mass in areas of need or competitive advantage.

A process of this sort is likely, over time, to result in an increased proportion of Australian Government research investment being allocated on a strategic basis so as to meet government needs for research.

This does not mean that government funding should be directed to applied, mission-based research to the exclusion of other forms of research. Even in the government's priority areas, much of the research will need to be early-stage, basic research, and much of the effort will be investigator-led. Furthermore, the government will continue support for investigator-led research across the disciplines in order to sustain a strong research fabric. Nevertheless the government will take a structured approach to articulating its research needs and ensure that its investment in research is effective in meeting those needs.



Optical fibre (courtesy of the Australian National Fabrication Facility)

134 Zients, JD and Holdren, JP (2012) *Science and Technology Priorities for the FY 2014 Budget*, Memorandum for the Heads of Executive Departments and Agencies, 6 June

10. IMPLEMENTING THE PLANNING PROCESS

ACTION 12:

- ARCom will implement and manage the national research investment planning process.
- ARCom will establish a mechanism for evaluating the national research investment planning process.
- ARCom will update the National Research Investment Plan at three-year intervals, or as required.

A NATIONAL RESEARCH INVESTMENT PLANNING PROCESS

Prime Minister Gillard has announced that the government wants to see Australia's schooling system in the top five of the world by 2025.[135] In making the announcement, the Prime Minister acknowledged that education needs to be a patient investment, but emphasised the great social and economic returns to individuals, and to the nation.

An excellent schooling system provides many benefits but, importantly, it is a vital resource for improving national wellbeing through research and innovation. To capture the full potential of excellent schooling, Australia needs to complement its investment in education with patient investment in research that is strategic and comprehensive; investment that will see Australia's research performance also ranked among the world's leading nations.

Historically, research investment decisions have been taken individually or, from time to time, as part of a larger policy initiative. For the first time, this Plan sets in place an ongoing planning process that will ensure future research investment decisions are comprehensive, sustainable and coordinated across government; a planning process that will achieve better research outcomes and better value for money. In summary, the planning process involves:

- the **objective** of guiding Australian Government research investment in a way that improves national wellbeing by increasing productivity and addressing Australia's key challenges;
- a framework, in the form of a **national research fabric**, that enables the development of Australia's research capacity and capability to be responsive to the needs of all sectors including business;
- a set of **research investment principles** that ensures government investments address the overall investment objective and are delivered efficiently; and
- a statement of **strategic research priorities** that enables investment to be focused on meeting the government's priorities.

135 Prime Minister the Hon Julia Gillard MP (2012), *A National Plan for School Improvement*, speech to the National Press Club, Canberra, 3 September

ARCom has the composition required to manage the research investment planning process and to achieve the necessary coordination across government. As reflected in this Plan, the initial actions for ARCom are to:

- prepare a statement of strategic research priorities;
- prepare a detailed plan to develop enabling capability in the five key domains;
- provide advice on a whole-of-government approach for opening access to the outputs and data from publicly funded research;
- propose measures to ensure the quality, quantity and skills of research trained staff will meet demand; and
- provide advice on mechanisms to support strategic international research collaboration.

In progressing these tasks, ARCom will further develop the evidence base upon which investment decisions are made, including by continuing to study the aspects of research supply and demand identified in its terms of reference.

Consistent with ARCom's whole-of-government advisory role, the government indicated in its July 2012 Rural Research and Development Policy Statement that it has asked ARCom to examine the level of coordination of Australian Government investment in rural research, development and extension.[136] The national research fabric provides a framework that allows such tasks to be integrated with broader research policy to give maximum impact and maximum value for money. ARCom will work with relevant parties to carry out this task in the context of coordinating government investment across the research fabric.

EVALUATING THE PLANNING PROCESS

ARCom will develop and implement a mechanism for evaluating the efficiency, effectiveness and appropriateness of the national research investment planning process. This process will draw upon Excellence in Research for Australia (ERA) data to assess research excellence in disciplines within and across Australia's higher education institutions, as well as other evaluations of research performance by public and private research organisations and R&D expenditure data collected by the ABS.

In addition to measuring the excellence, academic worth and academic impact of research outputs, the evaluation process will assess the broader economic, social and environmental benefits resulting from all elements of government research investment. A number of recent government reviews have recommended that government establish processes to measure impact, including the Research Workforce Strategy and the Prime Minister's Taskforce on Manufacturing.[137]

During 2012, DIISRTE undertook a feasibility study on possible approaches for assessing the wider benefits arising from publicly funded research. The study found that it would be feasible to introduce two new research impact mechanisms: one focusing

136 Australian Government (2012b), *Rural Research and Development Policy Statement*, 23 July

137 Prime Minister's Taskforce on Manufacturing (2012), *Smarter manufacturing for a smarter Australia*, Report of the non-government members, August

on universities and based around collection of case study and metric data, and another, more systemic, mechanism integrating administrative data collected by government departments and programs, publicly funded research agencies and universities.

Also during 2012, the Australian Technology Network of Universities and the Group of Eight (supported by DIISRTE) have been undertaking the Excellence in Innovation for Australia trial, to identify and demonstrate the contribution that high quality research has made to the economic, social, cultural and environmental benefit of society, and to investigate the means by which these benefits may best be recognised, portrayed and assessed by institutions and government.

ARCom will engage with existing work being done on impact assessment which will help in demonstrating the links between research investment and outcomes, and will be an important input to the development of an evaluation strategy.

INTERNATIONAL BENCHMARKING

The evaluation of outcomes from the planning process will include international benchmarking of Australia's research and innovation performance.

Australia is currently ranked behind about a dozen nations in terms of research intensity (ie, GERD/GDP), number of researchers, number of scientific publications and citation impact and ranked 18th by triadic patent families filed. Many of the leading R&D economies are similar or smaller in size than Australia. Apart from the US, Japan and Germany, the leading group comprises several Scandinavian countries plus Austria, Switzerland, South Korea and Singapore.

A policy of standing still will see Australia move backward in global terms as some two dozen countries have indicated an intention to lift their R&D expenditure to 2.5 per cent of GDP, or more. It is important to benchmark Australian research and innovation performance against a range of parameters to gauge our performance with respect to other countries.

UPDATING THE PLAN

The Plan emphasises the need for consistent policy and sustained investment. As funding programs should not be stop-start arrangements, neither should the planning process be a series of unconnected, one-off statements. The Plan and its implementation via ARCom provide an opportunity to gather experience that can be used, over time, to make better investment decisions and achieve generational change in Australia's research capability. ARCom will therefore review and update the Plan at three-year intervals, or as required.

APPENDIX A: NATIONAL RESEARCH INVESTMENT PLAN TERMS OF REFERENCE

The Australian Research Committee (ARCom) will develop a national research investment plan ('the Plan') for consideration by government by September 2012. The Plan will support future decisions by the government in relation to the level and balance of research investment for the period from 2013-14 to 2015-16. The Plan will consider, among other things:

- **a.** an overview of the location and capabilities of Australia's excellent researchers and innovators;
- **b.** areas of world class collaborative research activities;
- **c.** areas of demand by industry, government and other end users; and
- **d.** future priorities for major strategic research investments.

ARCom will review the Plan every three years, or as necessary, to support future decisions by the government in relation to ongoing research investment.

ARCom will be chaired by the Chief Scientist for Australia, and will consist of three elements:

- **a.** a senior Commonwealth Officials Group;
- **b.** an Expert Advisory Group to provide cross sectoral guidance, including the Chief Executive Officers of the Australian Research Council and the National Health and Medical Research Council and the National Security Adviser; and
- **c.** a group of publicly funded research agencies and other organisations responsible for delivering science and research funded by the Australian Government, including CSIRO.

The Expert Advisory Group and group of publicly funded research agencies will provide their advice to the senior Commonwealth Officials Group, which will in turn provide advice to the government via the Minister for Tertiary Education, Skills, Science and Research.

APPENDIX B: MEMBERSHIP OF ARCOM GROUPS

SENIOR COMMONWEALTH OFFICIALS GROUP

Professor Ian Chubb AC (Chair)
Australia's Chief Scientist

Ms Patricia Kelly
Deputy Secretary, Department of Industry, Innovation, Science, Research and Tertiary Education

Mr Phillip Glyde
Deputy Secretary, Department of Agriculture, Fisheries and Forestry

Ms Elizabeth Kelly
Deputy Secretary, Attorney-General's Department

Mr Ian Robinson
Acting Deputy Secretary, Department of Broadband, Communications and the Digital Economy

Dr Subho Banerjee
Deputy Secretary, Department of Climate Change and Energy Efficiency

Dr Alex Zelinsky
Chief Defence Scientist, Department of Defence

Mr John Kovacic PSM
Deputy Secretary, Department of Education, Employment and Workplace Relations

Ms Serena Wilson
Deputy Secretary, Department of Families, Housing, Community Services and Indigenous Affairs

Dr Rob Porteous
Assistant Secretary, Department of Finance and Deregulation

Mr Bruce Gosper
Deputy Secretary, Department of Foreign Affairs and Trade

Mr David Butt
Deputy Secretary, Department of Health and Ageing

Mr Barry Sandison
Deputy Secretary, Department of Human Services

Dr Wendy Southern PSM
Deputy Secretary, Department of Immigration and Citizenship

Mr David Williamson
Executive Director, Department of Infrastructure and Transport

Ms Marie Taylor
First Assistant Secretary, Department of Prime Minister and Cabinet

Ms Stephanie Foster
Deputy Secretary, Department of Regional Australia, Local Government, Arts and Sports

Mr Martin Hoffman
Deputy Secretary, Department of Resources, Energy and Tourism

Mr Malcolm Thompson
Deputy Secretary, Department of Sustainability, Environment, Water, Population and Communities

Ms Luise McCulloch
General Manager, The Treasury

Mr Shane Carmody
Deputy President, Department of Veterans' Affairs

EXPERT ADVISORY GROUP

Professor Aidan Byrne
CEO of the Australian Research Council (ex-officio)

Professor Warwick Anderson
CEO of the National Health and Medical Research Council (ex-officio)

Mr Philip Clark
Chair of the Education Investment Fund (EIF) Advisory Board

Dr Kate Fairley-Grenot
Adjunct Professor, Faculty of Agriculture and Environment, University of Sydney and Former Chair, Rural Research and Development Council

Mr David Miles
Chair of the Innovation Australia Board

Mr Brian Pink
Australian Statistician, Australian Bureau of Statistics

Dr Ron Sandland
Chair of the Australian Mathematical Sciences Institute (AMSI) Board, Chair of the Steering Committee of the Australian National Data Service (ANDS), and former Deputy Chief Executive of CSIRO

Ms Anne-Marie Schwirtlich
Director-General of the National Library of Australia

Mr Neville Stevens AO
Chair of the National ICT Australia (NICTA) Board and Chair of the Cooperative Research Centre (CRC) Committee

Professor Graeme Turner
Professor of Cultural Studies and Director of the Centre for Critical and Cultural Studies, University of Queensland

RESEARCH SECTOR GROUP

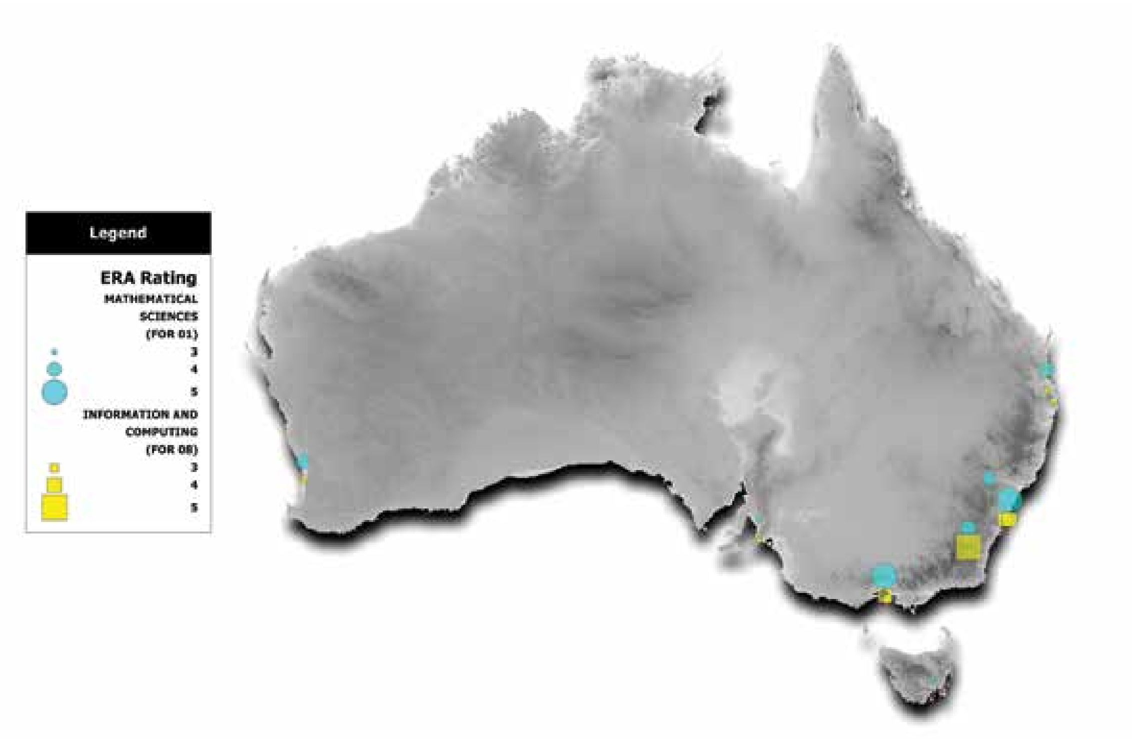
The following organisations are represented on the Group:

- Australian Antarctic Division
- Australian Centre for International Agricultural Research
- Australian Institute of Marine Science
- Australian Nuclear Science and Technology Organisation
- Bureau of Meteorology
- Commonwealth Scientific and Industrial Research Organisation
- Cooperative Research Centres Association
- Council of Rural Research and Development Corporations
- Defence Science and Technology Organisation
- Geoscience Australia
- Universities Australia

APPENDIX C: LOCATION OF EXCELLENT UNIVERSITY RESEARCH

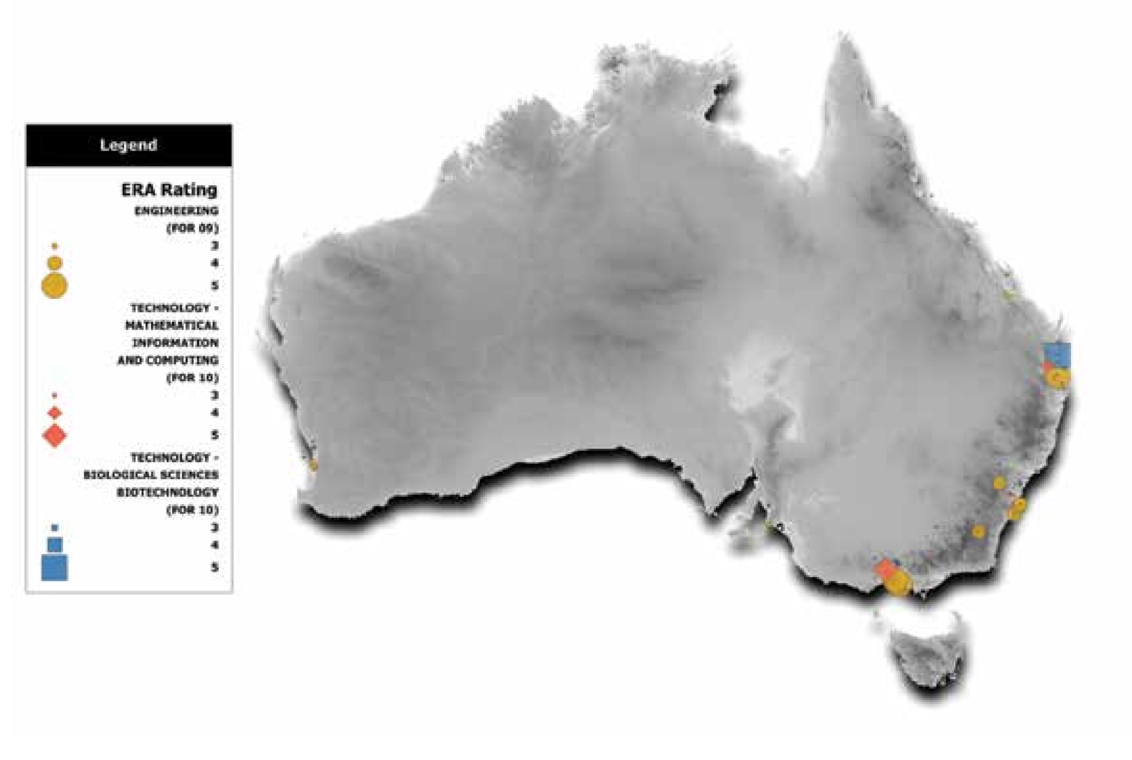
Location of Excellent University Research in Mathematical Sciences and Information and Computing

Source: ARC (2011), Excellence in Research for Australia 2010: National Report- Chart compiled by ANU Research Office 2012



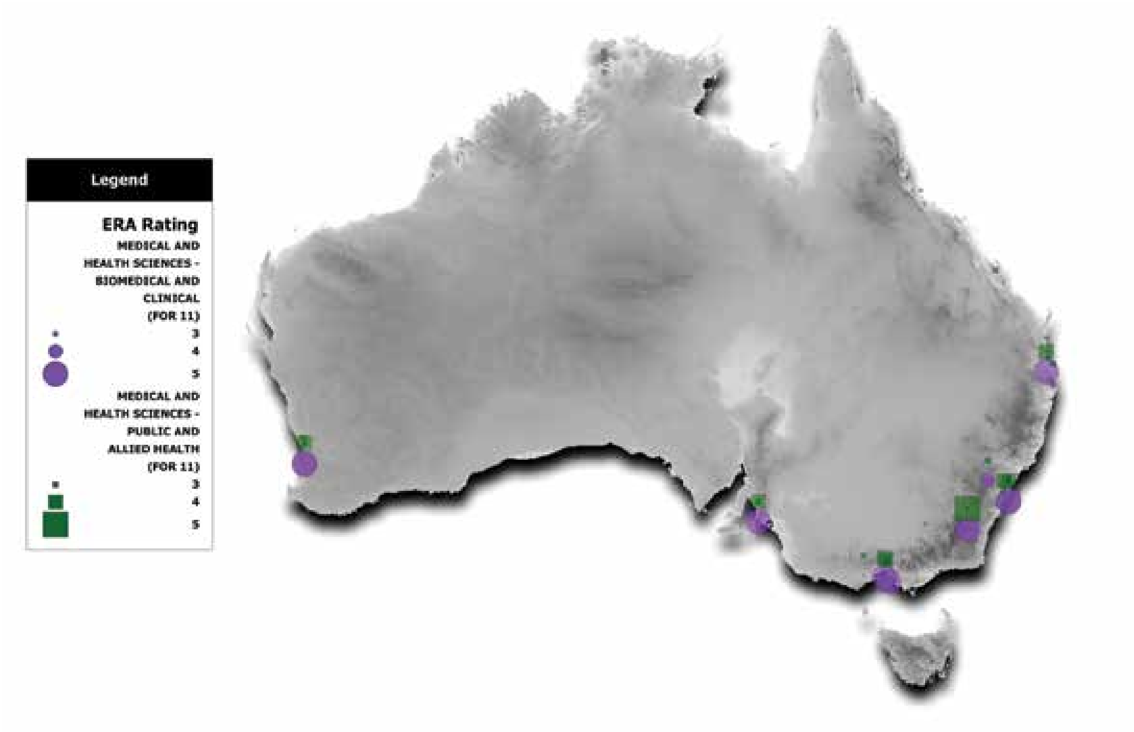
Location of Excellent University Research in Engineering and Technology

Source: ARC (2011), Excellence in Research for Australia 2010: National Report- Chart compiled by ANU Research Office 2012



Location of Excellent University Research in Medical and Health Sciences

Source: ARC (2011), Excellence in Research for Australia 2010: National Report- Chart compiled by ANU Research Office 2012

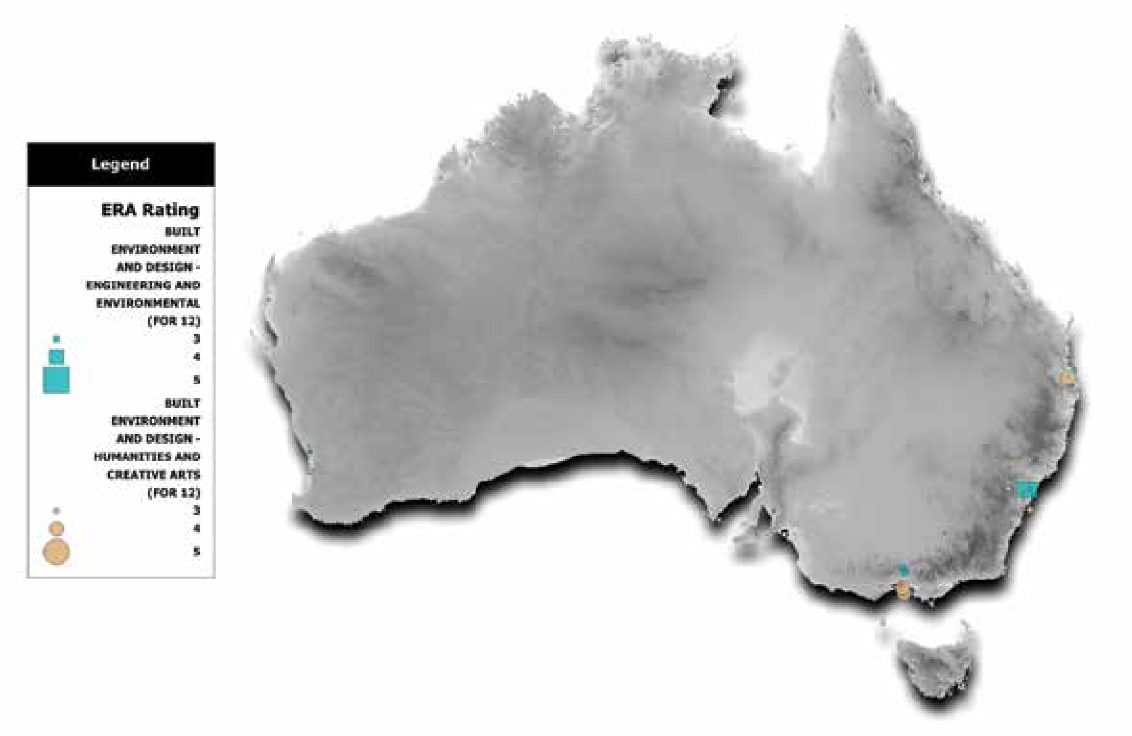


Location of Excellent University Research in Education, Studies in Human Society and Language, Communication and Culture

Source: ARC (2011), Excellence in Research for Australia 2010: National Report- Chart compiled by ANU Research Office 2012

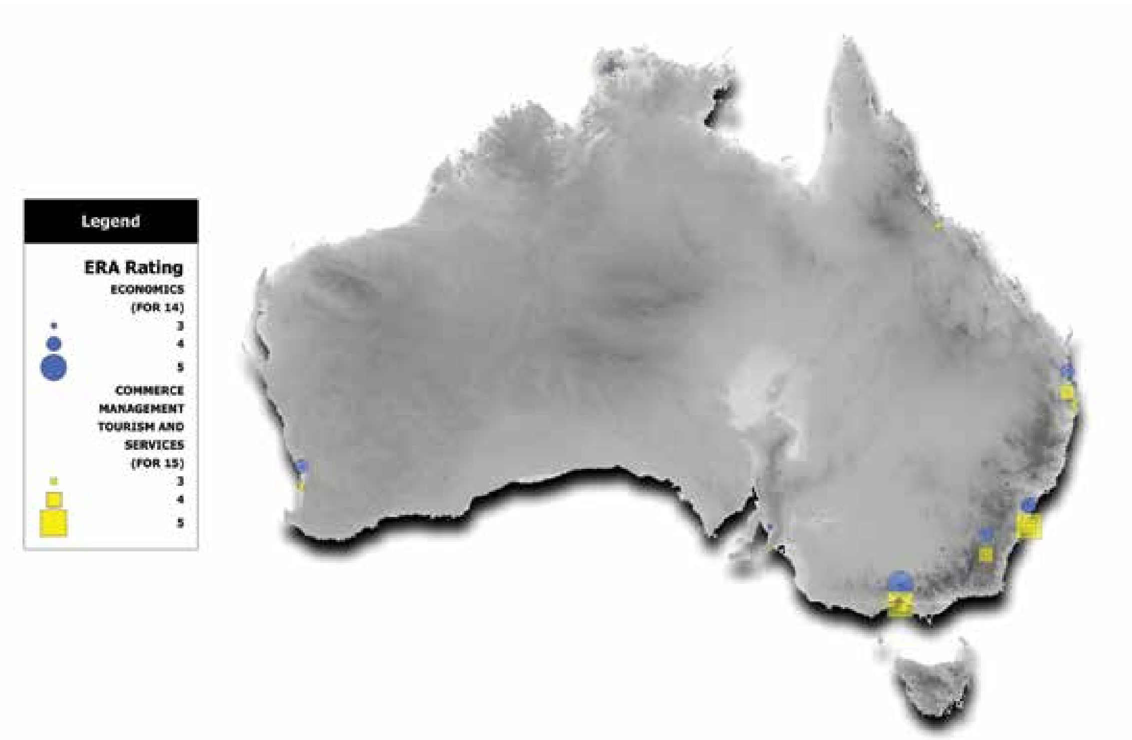
Location of Excellent University Research in Built Environment and Design

Source: ARC (2011), Excellence in Research for Australia 2010: National Report- Chart compiled by ANU Research Office 2012



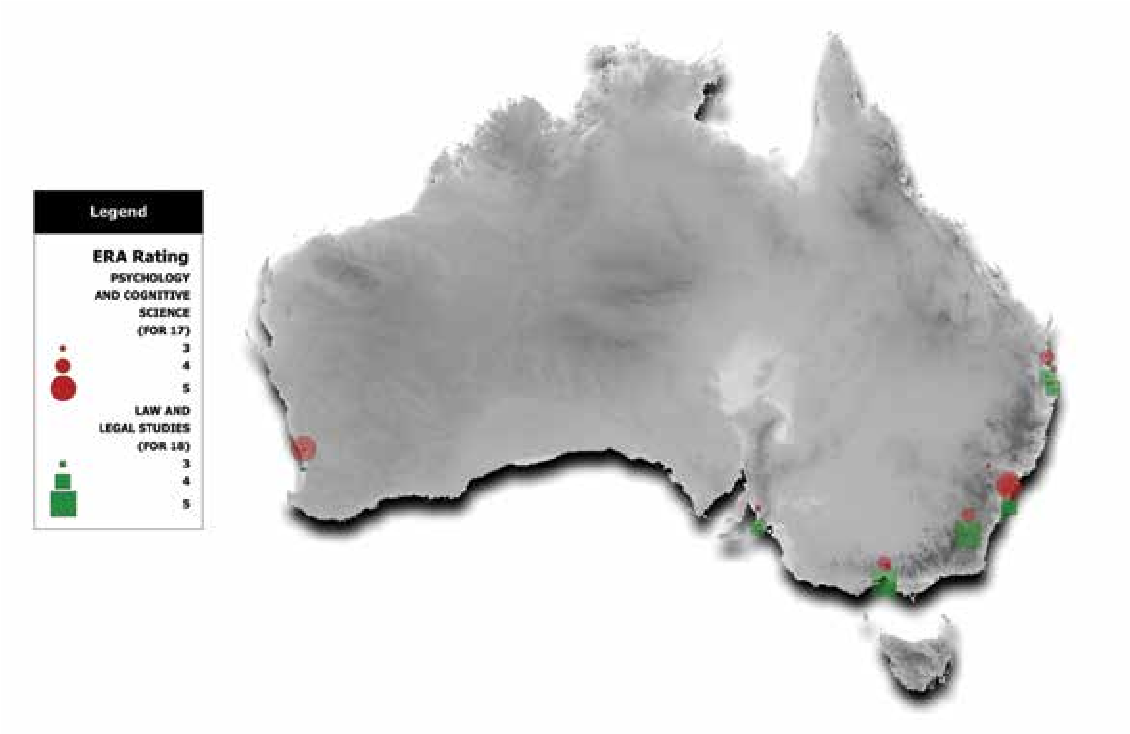
Location of Excellent University Research in Economics and Commerce, Management and Services

Source: ARC (2011), Excellence in Research for Australia 2010: National Report- Chart compiled by ANU Research Office 2012



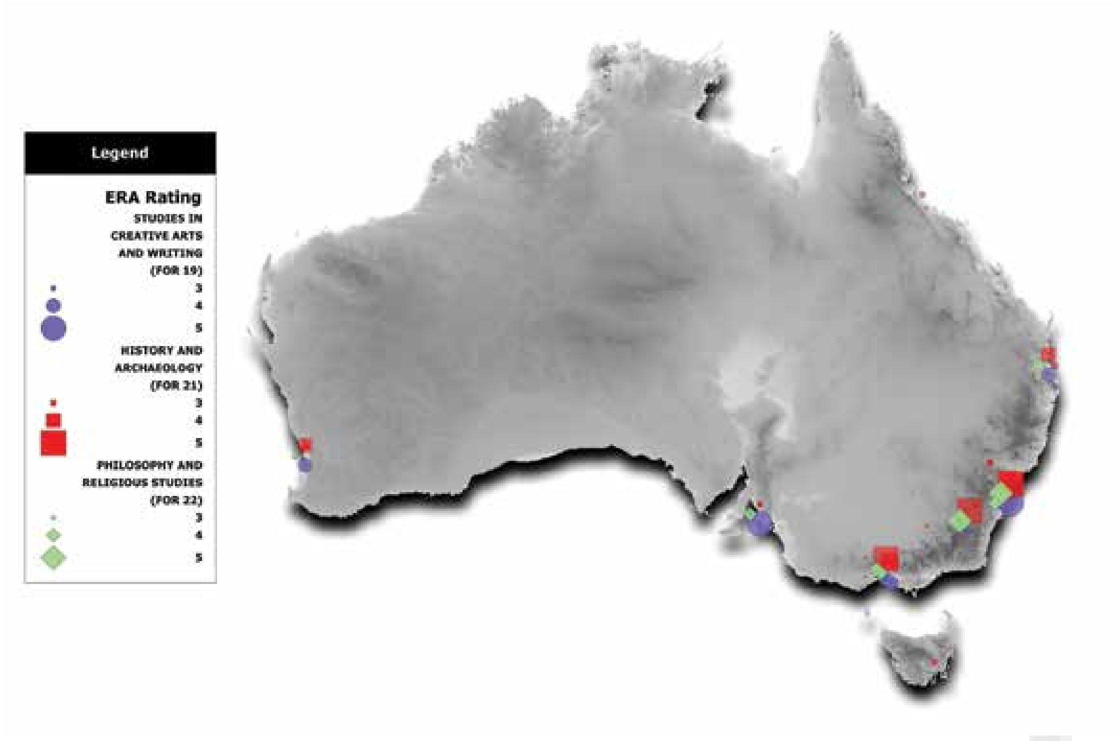
Location of Excellent University Research in Psychology and Cognitive Science and Law and Legal Studies

Source: ARC (2011), Excellence in Research for Australia 2010: National Report- Chart compiled by ANU Research Office 2012



Location of Excellent University Research in Creative Arts and Writing, History and Archaeology and Philosophy and Religious Studies

Source: ARC (2011), Excellence in Research for Australia 2010: National Report- Chart compiled by ANU Research Office 2012



APPENDIX D: AUSTRALIA'S GROSS EXPENDITURE ON RESEARCH AND DEVELOPMENT, 2008–09

Field of research	Business	GOVERNMENT			Higher education	Private non-profit	Total
		Commonwealth	State/ Territory	Total			
Engineering	9,118,212	597,031	13,731	610,762	577,160	—	10,306,134
Information & computing sciences	4,407,485	260,948	29,570	290,518	218,206	—	4,916,209
Medical & health sciences	938,374	82,818	368,731	451,549	2,064,348	559,338	4,013,609
Biological sciences	73,342	210,299	100,837	311,136	688,892	117,259	1,190,629
Agricultural & veterinary sciences	361,604	131,095	413,896	544,992	278,811	961	1,186,367
Technology	807,491	112,979	14,128	127,107	170,261	6,214	1,111,073
Chemical sciences	273,379	129,067	2,959	132,025	252,727		658,132
Environmental sciences	171,767	138,253	139,453	277,706	191,111	6,578	647,162
Earth sciences	196,425	193,650	45,772	239,422	194,548	—	630,395
Physical sciences	19,221	211,087	129	211,215	224,415	0	454,852
Built environment & design	319,252	13,864	1,575	15,439	68,925	—	403,616
Studies in human society		38,905	10,812	49,716	326,775	5,462	381,954
Commerce, management, tourism & services	100,862	1,958	3,143	5,101	253,793	—	359,756
Education	12,768	3,373	10,563	13,935	210,112	—	236,816
Psychology & cognitive sciences	4,088	19,035	3,389	22,424	199,480	6,700	232,692
Economics	12,229	36,076	2,506	38,582	162,719	—	213,530
Mathematical sciences	24,327	54,749	1,068	55,817	132,378	—	212,522
Language, communication & culture	1,627	32	2,263	2,295	161,510	—	165,432
History & archaeology		4,124	2,240	6,364	118,763	0	125,127
Law & legal studies	5,199	12,474	9	12,483	85,502	—	103,184
Studies in creative arts & writing	9,448	124	1,558	1,682	82,681	—	93,811
Philosophy & religious studies	0	0	196	196	53,994	—	54,190
Total expenditure on R&D	**16,858,477**	**2,251,941**	**1,168,527**	**3,420,468**	**6,717,113**	**743,907**	**27,739,965**

Source: ABS 8112.0 (2010)

APPENDIX E: SCIENCE, RESEARCH AND INNOVATION BUDGET TABLES, 2012

	Ref. no.	2003-04	2004-05	2005-06	2006-07	2007-08	2008-09	2009-10	2010-11	Estimated Actual 2011-12	Budget Estimate 2012-13
		$m	$m	$m	$m	$m	$m	$m	$m	$m	$m
Intramural Expenditure on Science, Research and Innovation											
Australian Government Research Activities											
CSIRO	1	568.6	577.1	593.9	610.1	663.1	675.8	714.8	730.3	724.9	736.8
Defence Science and Technology Organisation	2	293.9	315.4	351.1	408.1	406.0	379.5	407.6	421.7	462.2	439.5
Other R&D Activities	3	568.6	492.1	474.3	492.3	572.6	563.1	572.3	580.1	591.6	599.3
Sub-total		*1,431.1*	*1,384.6*	*1,419.3*	*1,510.5*	*1,641.7*	*1,618.5*	*1,694.7*	*1,732.2*	*1,778.8*	*1,775.6*
Extramural Expenditure on Science, Research and Innovation											
Business Enterprise Sector											
Industry R&D Tax Measures	4	665.0	729.0	897.0	1,005.0	1,156.0	1,429.0	1,455.0	1,445.0	1,906.0	1,833.0
Other R&D Support	5	219.5	175.0	191.1	212.2	234.0	179.3	64.5	43.8	16.6	13.5
Other Innovation Support	6	266.9	223.7	242.4	254.1	264.0	274.2	549.2	412.7	580.1	407.3
Sub-total		*1,151.4*	*1,127.7*	*1,330.5*	*1,471.3*	*1,654.0*	*1,882.5*	*2,068.7*	*1,901.5*	*2,502.7*	*2,253.8*
Higher Education Sector											
Australian Research Council	7	399.6	480.9	544.4	570.3	571.8	585.9	652.8	708.7	808.8	879.1
Performance Based Block Funding	8	1,322.5	1,333.0	1,383.2	1,400.4	1,391.7	1,408.4	1,514.0	1,661.4	1,774.6	1,907.4
Other R&D Support	9	449.1	8.2	139.8	9.6	12.1	15.7	202.9	225.4	167.1	58.5
Sub-total		*2,171.2*	*1,822.0*	*2,067.4*	*1,980.3*	*1,975.6*	*2,010.0*	*2,369.7*	*2,595.5*	*2,750.5*	*2,845.1*
Multisector											
National Health and Medical Research Council and Other Health	10	365.7	380.4	674.7	962.2	618.2	842.1	798.2	1,017.1	1,084.9	949.8
Cooperative Research Centres	11	201.8	194.5	208.1	189.3	211.9	182.3	178.9	172.6	165.5	154.1
Rural	12	226.3	225.7	234.0	238.5	241.4	245.7	228.8	220.8	264.8	256.0
Energy and the Environment	13	63.6	43.9	47.2	75.1	87.1	195.4	266.9	256.0	329.4	271.3
Other Science Support	14	60.3	71.7	93.8	172.8	175.3	187.7	400.4	579.0	393.6	429.2
Sub-total		*917.7*	*916.1*	*1,257.8*	*1,637.9*	*1,333.9*	*1,653.1*	*1,873.1*	*2,245.6*	*2,238.2*	*2,060.3*
Total Australian Government Support		**5,671.4**	**5,250.5**	**6,075.1**	**6,600.0**	**6,605.3**	**7,164.1**	**8,006.3**	**8,474.8**	**9,270.3**	**8,934.7**

APPENDIX F: AUSTRALIAN GOVERNMENT SUPPORT FOR SCIENCE, RESEARCH AND INNOVATION BY PRIMARY PURPOSE

Table F.1: Breakdown of Commonwealth Funding for Research Support Purposes – 2012-13[138]

Program		$million
Research Organisations		
CSIRO	736.8	
Defence Science and Technology Organisation	439.5	
Australian Nuclear Science and Technology Organisation	162.7	
Australian Centre for International Agricultural Research	116.7	
Geoscience Australia	113.8	
Antarctic Division	97.0	
Bureau of Meteorology Research Activities	32.8	
Australian Institute of Marine Science	31.6	
Other	53.3	
Research Organisations Sub-total		**1,784.3**
Agriculture, Fisheries and Forestry		
Rural R&D		241.7
DAFF Other		15.9
Broadband, Communications and the Digital Economy		
ICT Centre of Excellence		23.8
Families, Housing, Community Services and Indigenous Affairs		25.1
Health and Ageing		61.0
National Health and Medical Research Council		
Project grants		453.6
Industry, Innovation, Science, Research and Tertiary Education		
Joint Research Engagement Program		345.3
Sustainable Research Excellence in Universities		218.6
National Institutes Program - ANU Component		184.4
Other		24.1
Australian Research Council[139]		458.4
Sustainability, Environment, Water, Populations and Communities		
National Environmental Research Program		20.0

138 Based on Science, Research and Innovation Budget Tables - 2012.

139 Includes Discovery Projects (including Indigenous), Research Centres and Linkage Learned Academies Special Projects programs. 2012-13 breakdown of ARC funding has been calculated as a proportion of total funding as per the 2011-12 ARC funding breakdown.

Office of Water Science	15.0
Other	25.1
Resources Energy and Tourism	
National Low Emissions Coal Initiative	51.9
Other	40.0
Total	**3,988.1**

Table F.2: Breakdown of Commonwealth Funding for Workforce Development Purposes – 2012-13[140]

Program	$million
Industry, Innovation, Science, Research and Tertiary Education	
Research Training Scheme	656.1
Australian Postgraduate Awards	248.4
International Postgraduate Research Scholarship	21.5
Health and Ageing	0.3
Australian Research Council[141]	190.5
National Health and Medical Research Council	
Research (established career) fellowships	86.9
Early career fellowships	40.1
Career development fellowships	23.4
Postgraduate scholarships	11.0
International (exchange) early career fellowships	2.5
Total	**1,280.6**

140 Based on Science, Research and Innovation Budget Tables - 2012.

141 Includes Future Fellowships, Australian Laureate Fellowships, Discovery Early Career Researcher Award, Federation Fellowships and Super Science Fellowships programs.

Table F.3: Breakdown of Commonwealth Funding for Research Infrastructure Purposes – 2012-13[142]

Program	$million
Industry, Innovation, Science, Research and Tertiary Education	
Research Infrastructure Block Grants	233.1
Clean Energy Initiative	100.0
Education Investment Fund - Super Science	240.6
Education Investment Fund - Round 1	11.9
Education Investment Fund - Round 3	41.6
Education Investment Fund – Sustainability Round	27.0
Education Investment Fund – Giant Magellan Telescope	14.9
DIISRTE Other	27.6
Australian Research Council	34.6
Health and Ageing	52.8
National Health and Medical Research Council	
Infrastructure Grants	39.0
Enabling Grants	5.8
Total	**829.0**

Table F.4: Breakdown of Commonwealth Funding for Collaboration Purposes – 2012-13[143]

Program	$million
Industry, Innovation, Science, Research and Tertiary Education	
Cooperative Research Centres (CRC)	154.1
Collaborative Research Network Program	18.6
International Collaboration	16.2
European Molecular Biology Laboratory Partner Facility	2.0
Australian Research Council[144]	195.6
National Health and Medical Research Council	
Program Grants	116.4
Centres of Research Excellence	28.0
Partnerships for Better Health	12.0
International Project Grants	6.6
Health and Ageing	0.4

142 Based on Science, Research and Innovation Budget Tables - 2012.
143 Based on Science, Research and Innovation Budget Tables - 2012.
144 Includes ARC Linkage Projects and ARC Special Research Initiatives. 2012-13 breakdown of ARC funding has been calculated as a proportion of total funding as per the 2011-12 ARC funding breakdown.

Total	**549.9**

Table F.5: Breakdown of Commonwealth Funding for Business Research Purposes – 2012-13[145]

Program	$million
Automotive Transformation Scheme	240.8
Enterprise Connect	1.5
R&D Tax Incentives[146]	1,833.0
Total	**2,075.3**

Table F.6: Breakdown of Commonwealth Funding for Commercialisation/Translation Purposes – 2012-13[147]

Program	$million
Commercialisation Australia	60.7
Green Car Innovation Fund	57.7
Global Carbon Capture and Storage Institute	35.0
Innovation Investment Fund including Innovation Investment Follow-on Fund	32.3
Clean Technology Innovation Program	10.4
Development grants	10.1
Other	5.7
Total	**219.4**

145 Based on Science, Research and Innovation Budget Tables - 2012.
146 Includes R&D Tax Concession and R&D Refundable Tax Offset.
147 Based on Science, Research and Innovation Budget Tables - 2012.

APPENDIX G: RESEARCH WORKFORCE STRATEGY – VISION AND ASPIRATIONS

The government's vision for 2020 is of a strong and productive Australian research workforce, comprising the scale, breadth and depth of skills required to support innovation, educate the next generation of Australians, and ultimately drive productivity improvements across the economy.

It is underpinned by seven aspirations, targeting key factors influencing our ability to meet the immediate challenges of the decade ahead and position us for the many challenges and opportunities beyond.

These aspirations are that:

- Australian firms have access to the research skills and experience that will enable them to move up the value-chain and be globally competitive.
- Australia's public sector research organisations have a sufficient research skills base to support their diverse roles.
- Australia's higher degree by research (HDR) graduates have the skills and attributes to both engage in world-class research and make productive contributions in a wide spectrum of professional roles.
- Australian universities, as the major providers of research training in Australia, have sufficient numbers of research qualified staff to develop the next generation of researchers.
- Australian research students, researchers and research support staff are provided with clear and equitable pathways for career progression and supported to meet individual career needs and objectives.
- Australian research employers have in place the communication channels and linkages which promote the effective diffusion of knowledge (both codified and tacit) across the economy.
- Australia effectively draws on and harnesses the potential contributions of all research qualified individuals and facilitates participation in and engagement with the research workforce.

APPENDIX H: STRATEGIC FRAMEWORK FOR RESEARCH INFRASTRUCTURE INVESTMENT

Powering Ideas, the Australian Government's innovation agenda, aims to build a stronger national innovation system to assist in creating a better Australia – one that can meet the challenges and grasp the opportunities of the twenty-first century.

Powering Ideas included the creation of the National Research Infrastructure Council (NRIC) to provide strategic advice on future research infrastructure investments.

The *Strategic Framework for Research Infrastructure Investment* has been developed by NRIC in consultation with the research sector to guide the development of policy advice and the design of programs related to the funding of research infrastructure. The Council will undertake stewardship, promotion and championing of the Framework across the Australian Government and the States and Territories.

Investment in innovation and research drives productivity. Excellent research infrastructure, addressing national priority areas, is necessary to deliver high-quality research and innovation outcomes, to enable Australia to be globally competitive. The principles identified in this Strategic Framework will ensure that the approaches used to plan, fund and develop research infrastructure deliver the maximum contribution to economic development, social wellbeing, environmental sustainability and national prosperity.

PURPOSE OF THE STRATEGIC FRAMEWORK

The purpose of the Strategic Framework is to:

- identify principles to guide the development of policy advice and design of future programs related to the funding of research infrastructure;
- ensure that research infrastructure delivers the maximum outcome for the nation for the money invested; and
- improve consistency and coordination of Australian Government and State and Territory programs that support research infrastructure.

The applicability of the Strategic Framework principles will vary depending on the scale of the research infrastructure investment.

For the purpose of this Framework, investment in research infrastructure has been divided into three broad categories:

- Local – research infrastructure which could be expected to be owned and operated within a single institution.
- National – research infrastructure on a scale generally not appropriate to be owned or operated by a single institution and which often supports collaborative research and is generally regarded as part of the national research capability.
- Landmark – large-scale facilities (which may be single-site or distributed) that serve large and diverse user communities, are generally regarded as part of the global research capability, and engage national and international collaborators in investment and access protocols.

DEFINITION OF RESEARCH INFRASTRUCTURE

Research infrastructure comprises the assets, facilities and services which support research across the innovation system and which maintain the capacity of researchers to undertake excellent research and deliver innovation outcomes.

PRINCIPLES FOR RESEARCH INFRASTRUCTURE INVESTMENT

CONTINUITY OF FUNDING

- Research infrastructure funding programs should be ongoing and predictable, to achieve optimal use of funds.
- Infrastructure that continues to be a priority should be able to access funding for ongoing operations.

Guiding considerations

- *Ongoing and predictable funding programs support a more strategic, collaborative and planned approach to research infrastructure investment.*
- *Ongoing operational funding for priority national and landmark research infrastructure assists in maximising the benefit from the original investment.*

HOLISTIC FUNDING

- Funding required to support research infrastructure will vary between elements, including capital costs, governance, skilled technical support staff and operations and maintenance. Support should be available to cover these key elements.
- Funding programs should allow some funding for project development costs, either for a facilitation-based process or for project development and scoping activities.
- In the context where not all national and landmark infrastructure would necessarily be replaced, depreciation for these facilities should not be funded by Australian Government funding programs.

Guiding considerations

- *The ability to invest in human capital and operating costs results in superior service delivery and more efficient, productive and viable research infrastructure facilities.*
- *Funding for specialist staff assists in developing and maintaining the highly-skilled work-force required for the efficient operation of sophisticated facilities.*
- *Rigorous, consultative project planning is a key input to developing excellent research infrastructure facilities, particularly at the national and landmark scale.*

PRIORITISATION

- Any proposed research infrastructure investment should align with and support Australia's research, innovation and infrastructure priorities.
- Funding for Australia's research infrastructure should focus on areas where Australia:
  - undertakes world-leading research or innovation;
  - has demonstrated a particular strength in international terms; or
  - has reasons to seek to strengthen capacity in an area of research or innovation.
- Prioritisation of investment in research infrastructure is necessary to ensure appropriate, effective and efficient investment; to support strategic decision-making with regard to national and landmark infrastructure; and to ensure Australia achieves the maximum outcome for the money invested.
- Processes for funding research infrastructure should be transparent, provide effective use of funds and clearly target intended outcomes.

Guiding considerations

- *With finite resources, Australia needs to choose where to target its investments in research infrastructure.*
- *Australia needs to consider its priorities in both a national and an international context.*
- *Transparent processes to determine priorities will lead to better informed and more widely supported outcomes.*
- *The strategic identification of capabilities and priorities should be through a consultative roadmapping process every three years.*

EXCELLENCE IN RESEARCH INFRASTRUCTURE

- Proposals for investment in all scales of research infrastructure should be evaluated on the basis of their ability to create excellent infrastructure.
- Governance structures should be robust and fit for purpose to ensure the delivery of excellence in research infrastructure.

Guiding considerations

- *Excellence in research infrastructure is essential to ensuring Australia is able to continue to compete internationally and contributes to a strong innovation system.*

COLLABORATION

- Funding should favour investments that demonstrate collaborative approaches for the creation and development of research infrastructure and that foster and facilitate a collaborative research culture.

Guiding considerations

- *Collaboration is a key driver of innovation and is critical to ensuring the research community can deliver the outcomes Australia needs.*
- *There are often economic and efficiency benefits from taking a collaborative approach to establishing and operating research infrastructure.*

CO-INVESTMENT

- Co-investment in research infrastructure is desirable as it demonstrates a commitment by the investing party/ies to the project. Any program requirements for co-investment should be flexible to leverage maximum support.

Guiding considerations

- *Flexibility and transparency in co-investment requirements can lead to greater overall leverage and improves the ability of States and Territories to coordinate support for research infrastructure with the Australian Government.*
- *Opportunities for industry co-investment in research infrastructure facilities should be clear and encouraged as a basis for closer research collaboration.*

ACCESS AND PRICING FOR AUSTRALIAN-BASED INFRASTRUCTURE

- Research infrastructure at the national and landmark scale should be made widely accessible to publicly funded researchers.
- Research infrastructure at the local scale should be made accessible to the extent possible in order to maximise use and support collaboration between institutions.
- Pricing policies for research infrastructure should be clear and transparent and allow for flexibility in the charging model, while still maximising the public benefit.
- Access to and pricing of finite research infrastructure resources should be based on a combination of factors including merit, co-investment, the role of the host institution, opportunities for early career researchers, and supporting collaborative research.

Guiding considerations

- *An effective access regime ensures that research infrastructure is put to optimum use and fosters collaboration both nationally and internationally.*
- *An effective pricing policy for publicly funded research infrastructure ensures that meritorious research is not priced out of the market.*
- *Clear and transparent pricing policies allow for access costs to be built into research funding proposals.*

ACCESS TO OVERSEAS-BASED INFRASTRUCTURE

- Research infrastructure funding programs should consider Australian membership of, or contribution to the construction of, overseas facilities as the development of infrastructure in Australia is not always the most cost-effective solution to providing research infrastructure.
- Research funding programs should consider requests for funding Australian researcher access to overseas facilities.
- Where possible Australian research infrastructure facilities should be encouraged to provide access to International researchers to foster international links and collaborations and build local skills.

Guiding considerations

- *Funding access to overseas-based research infrastructure ensures Australian researchers can utilise the best infrastructure available and furthers Australia's engagement with the global research community.*

EVALUATION AND MONITORING

- Research infrastructure funding programs should incorporate procedures for regular and rigorous monitoring and evaluation to ensure the effective use of public funds.

Guiding considerations

- *Evaluation and monitoring is essential to determine whether the research infrastructure has delivered its desired outcomes and achieved its objectives over the short and medium term, as well as over its whole life-cycle.*
- *Consideration of whether the research infrastructure continues to be a national priority is assisted through rigorous evaluation.*

ABBREVIATIONS

AAD	Australian Antarctic Division
ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
ABS	Australian Bureau of Statistics
ACIAR	Australian Centre for International Agricultural Research
AIMS	Australian Institute of Marine Science
ANFF	Australian National Fabrication Facility
ANSTO	Australian Nuclear Science and Technology Organisation
ARC	Australian Research Council
ARCom	Australian Research Committee
BITRE	Bureau of Infrastructure, Transport and Regional Economics
BRICS	Brazil, Russia, India, China and South Africa
CERN	European Organization for Nuclear Research
CFC	Chlorofluorocarbon
CRC	Cooperative Research Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CSTACI	Commonwealth, State and Territory Advisory Council on Innovation
DEST	Department of Education, Science and Training
DIISR	Department of Innovation, Industry, Science and Research
DIISRTE	Department of Industry, Innovation, Science, Research and Tertiary Education
EIF	Education Investment Fund
ERA	Excellence in Research for Australia
EU	European Union
FoR	Field of research
FTE	Full-time equivalent
G20	Group of Twenty
GDP	Gross domestic product
GERD	Gross expenditure on research and development
HDR	Higher degree by research
HHF	Health and Hospitals Fund
ICSU	International Council for Science
ICT	Information and communication technologies
LIEF	Linkage Infrastructure, Equipment and Facilities scheme

MIT	Massachusetts Institute of Technology
MRI	Magnetic resonance imaging
NASA	National Aeronautics and Space Administration
NBER	National Bureau of Economic Research
NCRIS	National Collaborative Research Infrastructure Strategy
NGO	Non-government organisation
NICTA	National ICT Australia
NRP	National Research Priority
NSW	New South Wales
OECD	Organisation for Economic Co-operation and Development
PET	Positron emission tomography
PhD	Doctor of Philosophy
PMSEIC	Prime Minister's Science, Engineering and Innovation Council
PPP	Purchasing power parity
R&D	Research and development
SKA	Square Kilometre Array
TPF	Triadic patent family
UK	United Kingdom
UNESCO	United Nations Educational, Scientific and Cultural Organization
US	United States of America

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