Public Support for Science and Innovation

A submission to the Productivity Commission from CSIRO

July 2006

Terms of Reference

The following terms of reference were received by the Commission on 10 March 2006.

ECONOMIC, SOCIAL AND ENVIRONMENTAL RETURNS ON PUBLIC SUPPORT FOR SCIENCE AND INNOVATION IN AUSTRALIA PRODUCTIVITY COMMISSION ACT 1998

The Productivity Commission is requested to undertake a research study on public support for science and innovation in Australia.

Background

The Australian Government has identified science and innovation as one of its strategic priorities, recognising its contribution to Australia's economic and social prosperity. The Government has provided significant support for science and innovation, which it has augmented since 2001 through Backing Australia's Ability (BAA) , and funding now exceeds $5 billion per annum. In light of this investment, the Government considers that a study of public support for science and innovation is warranted. This study will complement the ongoing and planned reviews of BAA programmes.

Scope of the study

The Commission is requested to:

1. Report on:
   - the economic impact of public support for science and innovation in Australia and, in particular, its impact on Australia's recent productivity performance;
   - whether there are adequate arrangements to benchmark outcomes from publicly supported science and innovation and to report on those outcomes as measured by the benchmarks.

The analysis should cover all key elements of the innovation system, including research and development, taking into account interaction with private support for science and innovation, and paying regard to Australia's industrial structure.

2. Identify impediments to the effective functioning of Australia's innovation system including knowledge transfer, technology acquisition and transfer, skills development, commercialisation, collaboration between research organisations and industry, and the creation and use of intellectual property, and identify any scope for improvements;

3. Evaluate the decision-making principles and programme design elements that:
   - influence the effectiveness and efficiency of Australia's innovation system; and
   - guide the allocation of funding between and within the different components of Australia's innovation system;
   - and identify any scope for improvements and, to the extent possible, comment on any implications from changing the level and balance of current support;

4. Report on the broader social and environmental impacts of public support for science and innovation in Australia.

Although the Commission is not requested to review individual programmes, it can, where necessary, undertake case studies of particular types of public support for science and innovation. It should also draw on relevant international experience. The Commission is to produce a draft report and a final report within 12 months of the receipt of this reference. The report is to be published.

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Executive summary

Overview

The national innovation system (NIS) is a critical element of the Australian economy. Public support for innovation and specifically funding of scientific research makes a significant contribution to the system's overall performance.

This submission describes how public support for science and innovation produces a wide range of benefits that go beyond just direct economic impact. It argues that achieving these impacts requires a strong domestic science base and the effective operation of the NIS. The NIS is complex, and encompasses many organisations that have quite distinct roles and responsibilities, each of which needs to operate in ways that best allow them to meet their primary responsibilities.

Over recent years the Commonwealth Scientific and Industrial Research Organisation (CSIRO) has worked to clarify its role in the national system and has introduced new planning, management and evaluation procedures that increase its effectiveness and serve to maximise the return the government receives on its investment in CSIRO. These processes and governance arrangements have not only improved CSIRO's performance; they might also help address some of the impediments that exist in producing impact from publicly funded scientific research.

A more widespread adoption of these types of approaches could help improve the operation of other parts of the innovation system and thereby the system as a whole. This is important because changes in the global environment are placing ever greater demands on the publicly supported components of Australia's science and innovation systems.

Importance of science, technology and innovation

CSIRO produces science and technology. The innovation process through which these create commercial value (or improve social and environmental wellbeing) – is complex. It is important to recognise that:

- research-based, technical innovation is not the only form of innovation, but it provides the means of doing completely new things in different ways – it generates new opportunities, not just incremental improvements; and
- technical innovation requires the active participation, commitment and financial contributions of many players from outside the immediate research system.

Government expectations from research

An evaluation of the impact of public support for science should take into account the reasons for this support. Government supports science:

- to meet its own responsibilities in areas such as security, or environmental management;
- because market failure means private investment is below socially optimal levels;

- to take a long term leadership position, developing a capacity to respond when this becomes necessary, even though the immediate market signals for such research might be negligible; and
- to help fill niches in the innovation system that for historical or cultural reasons the private sector does not occupy.
    - Australia's lack of large corporate laboratories (reflecting the lack of very large firms) has emphasised the importance of CSIRO's role in performing strategic research.

Given this context it is not surprising (but important for the Productivity Commission's study) that Australian Bureau of Statistics data show that only 54 per cent of research expenditure by the commonwealth government has 'economic development' as its primary aim, while the equivalent figure for the higher education sector is only 29 per cent.

CSIRO's place in Australia's innovation system

CSIRO is a major player in Australia's research, science and innovation systems. It is one of the world's largest and most diverse public-funded research organisations with 6,500 staff (over 2,000 PhD qualified) operating on 57 sites across Australia, covering fields from advanced materials to ecosystem management, mineral exploration and processing to plant and animal sciences, and from climate science and water management to information and communication technology to astronomy.

In 2006-07 CSIRO will receive just over $600 million in direct appropriation funding, or just over 10 per cent of commonwealth support for science and innovation.

In addition to its appropriation funding, CSIRO generated non-direct appropriation (external) revenue of approximately $341 million in 2005-06, providing a total annual funding level of $935 million. It is important to note that CSIRO's expenditure stimulates further and significant private and public sector investment by bodies applying CSIRO research.

CSIRO's scale, diversity, and delivery of multidisciplinary research managed at the enterprise level for impact, differentiate it from other parts of Australia's research system. CSIRO adds to Australia's reputation and promotes its wellbeing by focusing its efforts around five core roles:

- addressing major national challenges and opportunities;
- creating new or significantly transforming industries to increase the competitiveness and sustainability of Australian industry;
- delivering incremental innovation to improve the efficiency and competitiveness of existing industries;
- providing fact-based solutions which meet community needs and knowledge that informs government policy; and
- advancing the frontiers of science.

Together with a number of satellite roles (such as in education and the management of national facilities and national collections) these provide the organisation with the means to deliver impact and develop capability to respond to new opportunities or events.

In contributing to Australia's scientific reputation, CSIRO helps to:

- provide privileged access to research performed in other countries;
- attract inwards foreign direct investment; and
- enable Australia to exert influence, including at important standards and other meetings that can have commercial significance.

Because CSIRO is a statutory authority it can represent Australia at intergovernmental meetings, which the private sector and universities cannot do.

CSIRO's unique role in the Australian research and innovation systems

Australia's research system encompasses the government, higher education and business sector:

- all receive public support but the different components and sub-components of the system should have their own distinct roles, responsibilities and objectives.
- because they aim to achieve different sets of outcomes, the various components of the research system should manage their research in different ways.

CSIRO plays a unique role in Australia's research system because of its scale, the diversity of the fields in which it conducts research, and its ability to plan, implement, manage and evaluate large-scale, multidisciplinary research that addresses major national challenges and creates new opportunities.

- multidisciplinary research is critically important because the increasingly complex problems facing society require complex, integrated responses that depend on scientific advances and innovation which often take place at the intersection of different scientific disciplines.
    - CSIRO is able to implement a comprehensive, multidisciplinary response because of the breadth of its capabilities, the frameworks it has developed to manage large projects and the internal mobility of its resources

While CSIRO plays a significant and unique role, the importance of which has increased over recent years, its proportional contribution to Australia's total research effort has decreased over the last 20 or 30 years as both universities and business have increased their research expenditure, in both cases fuelled by increasing government support.

CSIRO's scale of operations gives it domestic and international visibility, while its breadth of expertise allows it to take a broad view in considering how best to tackle a problem.

- This helps CSIRO play a major role in developing and maintaining Australia's capacity to respond – its ability to create and maintain the options for action that are essential, given the rapid pace of change and the levels of global uncertainty that Australia faces.
    - This capacity arises as a by-product of activities that are producing more direct outputs and impacts.

An important benefit of CSIRO's scale and scope is that in combination with the organisation's appropriation funding and business models they allow the organisation to manage its own risks and help Australian business to manage its research risk. It achieves this by:

- maintaining a portfolio of projects across different fields and different stages of development; and
- entering into co-investment or joint funding arrangements with industry and other stakeholders to achieve targeted outcomes.

In fulfilling its various roles and in harnessing its scale to plan and implement large, multidimensional programs, CSIRO relies on its appropriation funding:

- grants and contracts, while important, do not provide a sound basis for large scale, long term research; or for developing the sustained relationships and trust, with all parts of the innovation system, that are necessary to make a significant difference to Australia;
- a complete dependence on grants can have an adverse impact on important basic capabilities as some argue has happened with New Zealand's Crown Research Institutes;
    - moreover, using and administering grant schemes can have high transaction costs, especially given the often small proportion of applications that receives funding. This can affect the efficiency of the public support processes and is an important issue in designing support programs.

CSIRO's way of operating with its customers and partners:

- provides opportunities to share risks and rewards with partners, including the private sector; and
- has the intent of ensuring that the organisation does not use public funding for work that the private sector would otherwise conduct itself.

CSIRO – innovating to increase impact

CSIRO has always worked to increase the return the government receives on its investment in the organisation. Over recent years in particular, CSIRO has built on the single point accountability provided by its appropriation funding to introduce more effective planning, management and evaluation processes. These processes:

- build on an explicit understanding of CSIRO's purpose and role in the national innovation system;
- ensure the quality of the organisation's underlying capabilities;
- are transparent (delivering accountability to taxpayers), operate at the enterprise level and introduce path to application considerations from the planning stage;
- involve scanning and analysing the external environment and assessing the capabilities of both CSIRO and Australia, to ensure that CSIRO allocates its funds only to research that will have impact;
- involve the early and continuing participation of external stakeholders, at the strategic level as well as in relation to research management;
- actively manage the research for impact, as well as for scientific excellence; and
- help increase and improve the CSIRO's technology transfer capabilities.

A world class set of scientific research capabilities and associated infrastructure underpin the scale of CSIRO's research effort and its management for impact.

The active management of its research portfolio, supported by continual monitoring of both science achievements and the path to impact, facilitates the reallocation of funds to those areas of research most likely to improve Australia's economic, social and environmental wellbeing and not just succeed in scientific terms. The organisation is also using more sophisticated approaches to technology transfer and better focussing its activities on the generation of impact through these activities.

- CSIRO's National Research Flagships provide the best and most advanced examples of these processes working together and provide a good pointer to future increased impacts.
- CSIRO's Australian Growth Partnership model for technology transfer to SME's is another potential outcome-oriented mechanism that has emerged from the organisation's increased focus on the path to impact. The model seeks to address some of the absorptive capacity limitations of Australia's industry structure.

The mechanisms CSIRO has built to manage its research outcomes, to support its capabilities and to further develop them, enable the organisation to deliver impact while at the same time preserving the option value of being able to redeploy this capability on new and emerging national needs.

Evaluating CSIRO's impact

The organisation's annual reports and many other publications provide examples of CSIRO's achievements and impacts.

- The approach has been to use a variety of different impact measures collected using a range of methodologies.
- While each by itself has deficiencies, together they have helped build a picture of CSIRO's breadth of impact and demonstrate that the benefits CSIRO produces are significantly greater than the funding it receives.

Data presented in this submission demonstrate CSIRO's high standing in scientific terms as shown both by citation data and external peer review processes. They also illustrate the variety of impacts CSIRO has made across a broad range of economic, environmental and social areas.

While these historical attempts to measure impact provide useful data, CSIRO has recognised that they all have limitations, especially when dealing with research that has multiple objectives, achieves impact through a variety of routes and builds on a capability that the organisation can readily redirect to other purposes.

- For this reason CSIRO is currently working to understand better the advantages and disadvantages of different impact measures and to develop an overarching real options impact analysis framework.
- As well as providing a more sophisticated analysis of the impact that CSIRO is having, this process will inform the further refinement of the organisation's decision making and assessment processes.

CSIRO responding to impediments in Australia's innovation system

CSIRO works with its partners and stakeholders to overcome impediments to achieving greater impact that is under its control, although many of these require a broader approach to address them successfully. Significant impediments faced by the organisation in seeking to achieve greater impact include:

- cultural differences provoking different perspectives
- availability of high risk venture capital;
- the dynamic and complex nature of the NIS;
- inappropriate performance measures;
- a lack of role clarity, appropriate governance and research management processes among various components of the innovation system;
- Australia's geographic location and economic structure;
- globalisation and the increasingly competitive nature of the global innovation system;
- the absorptive capacity of industry and other technology users;
- the supply of appropriately skilled people and entrepreneurs; and
- technological literacy.

The importance of ongoing support and reform

The changes taking place in Australia's region, and more generally in the world, clearly point to the need for Australia to develop a more diversified economic base and in particular to develop a greater capacity with respect to knowledge based industries. As shown by policy decisions taken by other countries, this will require greater national expenditure on science and innovation.

Given the structure of Australia's economy and existing industry base, responding to global challenges will require increases in the level of public support for science. Based on its recent experience and its assessment of the global challenges that Australia is facing, CSIRO believes that additional investment should be increasingly targeted to support research explicitly managed for impact.

Recognising the importance of diversity, correctly harnessed, an important precondition for increased investment, however, needs to be the active promotion, across the innovation system, of arrangements that lead to each component of the system:

- clarifying its role and purpose, to differentiate it from other parts of the system and to allow it to concentrate on what it can do best;
- collaborating with other organisations when these have the complementary skills, characteristics or infrastructure necessary to do a job well;
- managing its research for impact, concentrating on achieving those impacts that flow from its agreed role;
- using transparent governance processes that deliver accountability to taxpayers while providing the data and information necessary to support internal research planning, management and evaluation processes; and

- focussing on the quality of its underlying capability, given the purpose of that capability and the complementary assets available elsewhere within the Australian research and innovation systems.

Putting these types of processes in place across the broader innovation system, and supporting them through a diverse range of clearly differentiated funding and other support mechanisms, managed according to what they aim to achieve, would help reduce unnecessary duplication, increase accountability by increasing transparency, and improve the efficiency and effectiveness of the national innovation system.

Introducing management and governance processes that best allow the individual components of the innovation system to fulfil their particular roles would provide a more explicit base for the active evaluation of both institutions and publicly supported research. This would help generate the range of impacts the government is aiming to achieve through the support it provides. It could also help increase the effectiveness of Australia's national innovation system.

Introduction

CSIRO is Australia's largest public sector research organisation. It is a commonwealth statutory authority established by the *Science and Industry Research Act 1949*, which sets out its functions (Attachment 1).

In 2006-07, CSIRO will receive $607.2 million in appropriation funding, or just over 10 per cent of the total commonwealth support for science and innovation of $5 974 million.[1] (The higher education sector will receive $2.23 billion of this, the business enterprise sector $1.25 billion.)

In addition to its appropriation funding, CSIRO anticipates generating non-appropriation (external) revenue of $362.8 million, providing a total budget of $970 million for the year.[2] This compares to Australia's total R&D expenditure of $12 250 million in 2002-03.[3]

The table below shows the source of CSIRO's non-appropriation revenue from its co-investment, consulting and services work in previous years. The table demonstrates the diversity of the organisation's customer base and that CSIRO has links with all parts of the national innovation system.

Industry Category ($ m)	2005-06
Australian Private (Large)	42.1
Australian Private (SME)	29.1
Commonwealth, State & Local Govt	86.7
Australian Universities	7.7
R&D Corporations	44.3
Co-operative Research Centres (CRCs)	35.2
Overseas Entities	35.0
WIP / DR adjustment*	-8.0
Total Coinvest, Consulting & Services	272.1

* adjustment for work in progress and deferred revenue

The direct (appropriation and non-appropriation) funding received by CSIRO stimulates further and very significant private and public sector investment by bodies using CSIRO developed science and technology in their innovation processes.

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[1] The Australian Government's 2006-07 Science and Innovation Budget Tables http://www.dest.gov.au/ministers/bishop/budget06/scitables.pdf;
CSIRO portfolio budget statement
http://www.dest.gov.au/portfolio_department/dest_information/publications_resources/resources/budget_information/2006/pbs.htm.

[2] Non-appropriation funding includes government funding through grants and contracts, private sector funding (eg contracts), intellectual property revenue and revenue from sales of assets.

[3] 8112.0 - Research and Experimental Development, All Sector Summary, Australia, 2002-03.

CSIRO is clearly a very major player in Australia's national innovation system, in terms both of its receipt of government support and its overall contribution to Australia's total research effort.

The scale and diversity of CSIRO's operations also differentiate it from other parts of the research system. They enable CSIRO to establish world class teams that can take a truly multidisciplinary approach. This allows the organisation to plan, manage and deliver mission-directed strategic research (driven by intended impact rather than curiosity) to provide integrated solutions to national challenges, take advantage of emerging opportunities and create new opportunities. This research can be large scale and long term. However, CSIRO is able to manage it for impact and relevance while reducing risk by redeploying resources if it becomes apparent that the research cannot achieve its intended outcomes. This is because CSIRO increasingly operates as a single enterprise with single point accountability, rather than as a collection of independent units.

CSIRO has impact through the research that it performs, the scientific infrastructure that it supports, the training and education that it provides, and the technical and other services that it makes available. As well as the direct impact of these activities, they together create a capability that the organisation can deploy in response to new or unexpected opportunities or events. While some of CSIRO's activities can have a direct impact, others depend on the organisation working directly or indirectly (and with differing degrees of formality) with other parts of the innovation system. Research performed by CSIRO creates opportunities and options for other players in the innovation system. The conversion of science into technology or technology into commercial or other outcomes often depends on partnerships and cooperation. Impact at all levels can depend on the linkages, interactions and other arrangements that reflect CSIRO's position as one component of a large and complex national innovation system.

In providing this submission to the Productivity Commission's study, CSIRO will not attempt to review the extensive theoretical, economic and other policy literature on the relationship between research, innovation, productivity and economic growth.[4] Instead, the submission explores the particular roles that CSIRO plays in Australia's research and innovation systems so as to identify the impacts it strives to achieve, the mechanisms it uses to produce these impacts and the changes it is making to increase the return on the considerable investment the public makes in CSIRO's operations.

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[4] Steve Dowrick's August 2003 paper, *A review of the evidence on science, R&D and productivity*, prepared for the Department of Education, Science and Training, provides a useful review of recent economic and statistical studies. An important conclusion of this review is that macroeconomic studies that distinguish between public and private sector R&D and which allow for longer lags for the latter to affect productivity, find that public sector R&D contributes significantly to productivity, albeit less strongly than private sector R&D. This submission argues that it would be surprising if public research did not have a lesser impact on productivity than private sector research, given the purpose of public sector research and the arguments for government support. Dowrick's review of the economic literature also concludes that business R&D is complementary to public sector civilian R&D – raising investment in one sector stimulates the productivity of the other.
http://www.dest.gov.au/sectors/science_innovation/publications_resources/profiles/review_evidence_science_productivity.htm (14.4 KB)

This submission will argue that a number of the changes CSIRO has made to the way it operates would also generate greater benefits if applied more widely across the NIS.

This submission argues that Australia needs a broad-based, diverse and balanced national innovation system, the importance of which is increasing as the world becomes more uncertain; and it demonstrates that government support is essential to achieve such a system.

The submission starts with some scene setting by defining basic terms and explaining the importance of a strong domestic science base. It discusses the reasons the government provides support for science and innovation and notes the ways in which this sets boundaries on the impacts that such support might produce.

The submission then outlines some characteristics of Australia's research and innovation systems, noting in particular those that create the need for an organisation such as CSIRO.

There is then a more detailed discussion of the roles and responsibilities of CSIRO with details of how it assesses its impact and is striving to increase the return the nation receives from the investment the government is making in CSIRO. The submission provides some examples of the broad range of measures that CSIRO has used to assess its impact and which demonstrate the important contributions that CSIRO is making to Australia's wellbeing.

This is followed by a general discussion of impediments to the effective functioning of the innovation system and what actions CSIRO is itself taking to help overcome or remove them.

With its focus on CSIRO, this submission complements the more general submission made by CSIRO's portfolio department, the Department of Education, Science and Training.

CSIRO will be making a supplementary submission to the commission in August, following the completion of a more detailed, rigorous and quantitative assessment of CSIRO's impact using a real options analysis framework.

The importance of innovation

Some definitions

In examining the impact of public support for science, technology development and innovation, it is important to understand the meanings of these terms and the relationship between them. While in practice the boundaries between these activities can become indistinct, there are differences between them that have a major bearing on the impacts that they can and should have.

Science

Science is a body of knowledge which creates an understanding of how our world, the universe, works and the impacts that we have on it. The process of generating and advancing scientific knowledge is known as research. One characteristic of scientific knowledge is that it is generally applicable anywhere, by anyone who has the expertise necessary to understand it.
Advances in knowledge can diffuse very quickly and the changed understanding this produces can create potential for further research and technology developments, often outside the immediate field of research that led to the original advance. Another important characteristic of knowledge is that once it is available, there may be no cost in anyone using it to develop and improve their own understanding.

Most advances in science are incremental and help refine or confirm what we already know. However, a major scientific development (and the paper that reports it) can revolutionise our current understanding of the world and point to previously unimagined opportunities. Anyone (and everyone) in the world with access to the paper and the necessary expertise can read the paper. If the paper is well written, soundly based and credible, it can dramatically change the way the reader perceives the world. This change in understanding does not cost anything, apart from the mental energy necessary to achieve it. The advancement of knowledge in this way is one of the important cultural impacts of science and is an inevitable impact of the publication of science.[5]

Advances in knowledge may well have short, medium and longer term consequences in terms of the decisions made and actions taken by those with the new understanding.[6] Moreover, scientific advances are cumulative, building on what went before. This means that the impact of scientific research can be pervasive and difficult to identify.

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[5] The degree to which any single paper can develop understanding depends on the receptiveness of its audience. A paper describing a significant scientific advance might have little impact because those reading it do not appreciate its significance – as with Mendel's work on genetics or Wegner's work on 'continental drift'. On the other hand, a paper such as the (very short) 1953 paper of Watson and Crick describing the structure of DNA had an immediate global impact that has continued to this day. There is an absorptive capacity issue for science, just as there is for technology. The discovery by Barry Marshall and Robin Warren that bacteria cause stomach ulcers and gastritis led to a major advance in understanding with very practical consequences but there was certainly some resistance to accepting the results.

[6] An interesting example is the way in which research that developed the concept of ecosystem services has had an impact on the decisions made by natural resource managers.

Our current understanding of molecular genetics (and the applications that this has inspired) still stem from discoveries made over 50 years ago about the structure of DNA. Researchers studying the interaction of light with atoms had no plan to produce lasers (or the CD and DVD players, surgical instruments or sewer alignment technologies that stem from them). Early workers on the structure of the atom and the development of quantum mechanics did not foresee the development of transistors and integrated circuits. Advances in knowledge can create opportunities beyond those that the researchers themselves might conceive, quite apart from any serendipitous outcomes. However, when a scientist makes a significant advance in understanding, this can have a direct impact very quickly. Recent examples include CSIRO work on rising sea levels; or on the impact and potential consequences for climatic change of ocean acidification resulting from human activity on calcifying organisms.

Technology

Science is usually coupled with technology. However, while science is a process for understanding the world, technology provides a means to change the world. It is possible to use some (but not all) of the knowledge created by science to develop ways of doing things. Technology provides the means whereby we can do things in new, different, better or more efficient ways. Technology applies scientific knowledge for a purpose. The process of using scientific knowledge to develop technology is invention and invention is another form of research.

Technology differs from science in that its acquisition and use are often both more complex and more expensive. Because it is a way of doing something, technology (and particularly industrial technology) tends to be more local in its application than science and has to build on or change existing ways of doing things. This is expensive and in principle more difficult than changing the way scientists think. However, one consequence of this is that it is often easier to identify the impacts of technology than of science. While technology can often be quite local in its application, some technologies can have significant flow on effects in creating further options for work and application. Technologies applied in scientific research (such as the invention of the mass spectrometer) provide obvious examples.

Technology development normally draws upon a strong science base and makes use of scientific advances. However, the pathway between the science and technology is not always direct and can sometimes be difficult to discern. Moreover, in some cases technological advances can take place in advance of scientific understanding. It is a mistake to assume some kind of linear relationship between science and technology.

Innovation

The process of applying technology to create value is known as technical innovation. This is a central concept in examining the ways in which public support for science can have economic, social or environmental impact. However, it is important to recognise that innovation extends beyond technology and that non-technical innovation can itself be critical to the effectiveness of technical innovation.

In its broadest sense, innovation is the introduction of change to improve performance. The change may involve the introduction of new technologies, whether they are processes or products. The change could equally involve, for example, new, management systems, company reorganisation, a decision to enter (or leave) specific markets, or to introduce performance based pay or a novel set of performance indicators. However, in all cases innovation is about exploiting ideas and doing things in new ways to create value. Depending on the nature of the organisation, it might be capturing increased value through its economic, environmental or social performance. An innovation might be new to the organisation, the nation or the world.

Most innovation is incremental, building on existing systems and products and taking up ideas that other organisations are already using. Incremental innovation is important and can help maintain or increase a firm's competitive position and market share, or help ensure its survival. However, it is the major or 'radical' innovation, which sets new directions and creates the completely new opportunities that provide a genuine foundation for progress. In most cases radical innovation is technical innovation that draws on exciting, breakthrough science and originates in strong, excellent, applied research and development. Innovation makes use of the capabilities and potentialities that science has created.

Technical innovation requires a different set of skills, expertise and capabilities from those required to perform research.[7] Innovation is a complex process that requires the participation of many players with diverse but complementary skill sets, different cultures, different expectations and using different performance measures. Research is often a relatively inexpensive part of the overall innovation process; and the financial, political and commercial risks tend to increase significantly as the process proceeds.[8]

Innovation takes place in a different context from that in which invention flourishes. If the complementary resources needed to transform an invention to an innovation do not exist or are not available, it may not be possible to use the research outputs effectively. For example, there is little point in performing research to develop technology if the finance necessary to apply the research is unavailable. There is no point in performing research if those able to use the research outputs have no commitment to do so or lack the necessary financial, technical, managerial or marketing skills. Neither is there any point in promoting technical innovation to help increase the competitiveness of an industry if the main factor limiting its growth is market access, a complex regulatory environment or changed consumer preferences.

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[7] Incremental innovation requires a different set of skills and approaches from those necessary for radical innovation. William L Miller has recently suggested that managers of incremental innovation need to worry about product, price, place and promotion; while managers of radical innovation have to focus on product, process, people and politics. (*Research Technology Management* 49(2) 2006)

[8] Robust data to support the view that $1 spent on research leads to $10 on development and $100 on commercialisation is hard to find and in any case the costs of moving from invention to innovation show considerable variability. Nevertheless, it is well to remember that any investment in research is going to require significantly greater investment (usually from other parties) to capture effectively the benefits of the research. Moreover, the risks of commercial failure are often greater than the technical risks of the research.

Discussions of technical innovation often focus on the direct economic outcomes of commercialising technologies or otherwise transferring them to market. However, innovation can also take place in the non-market parts of the economy. For example, a better understanding of environmental processes can lead to changed management practices that maintain diversity, increase sustainability or prevent degradation (and losses in productivity) that might otherwise occur. Health research can improve general wellbeing and people's quality of life.

Measuring the impact of this innovation directed towards social and environmental wellbeing can be difficult, not least because different people may value what they gain or lose in quite different ways. Land developers or hunters may put a very different value on conservation initiatives than conservationists. In these circumstances the decision to make use of the science is made by politicians, not the market. The science helps identify the full consequences of the various options available to the decision makers but does not necessarily point to a single outcome.

The benefits of science

Investment in research can advance science and lead to the development of technologies in the form of new products and processes that provide the feedstock for technical innovation. National self interest can be a major reason for the government supporting research to develop technologies that will improve the competitiveness of manufacturing firms or that will address major environmental or health problems. However, it is important to recognise that scientific research has impacts that go beyond a direct contribution to innovation or economic development. These other impacts provide part of the justification for government support.

Research can produce significant national benefits across a wide range of areas. These benefits may be intangible, as well as tangible – but this does not decrease their importance. This submission has already mentioned the cultural significance of science and that some government support for basic research comes from a genuine commitment to advance knowledge as a cultural activity in its own right. Astronomy provides an obvious example (although even here the early development of the science flowed from practical needs relating to navigation and the development of calendars). However, governments also recognise that this type of research plays an important role in developing human capital; and that serendipitous discoveries can have very significant economic impact, even though it is impossible to plan them.[9] The most important purpose of research is not just to respond to opportunities but to create them.

The cultural significance of science and the way in which investments in science can create national pride and international prestige becomes very apparent in the case of governments supporting space exploration or high energy physics. Environmental research that helps us to appreciate the unique characteristics of the Australian environment, its plants and its animals provides another obvious example of research that has a profound cultural impact beyond its utility in helping manage the environment.

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[9] As discussed later, basic research is also the research least likely to receive funding from the private sector. At the same time, it is the research most likely to produce extensive spillover benefits. This market failure presents a strong argument for government support.

International prestige is not just a matter of the way in which other nations or their people view Australia, important though this can be. In a very real sense, international science is a 'trading network' in which nations are able to access the knowledge produced by others according to the level at which they are contributing.

Working in a country that other scientists recognise as having an excellent scientific reputation provides opportunities for both direct and indirect collaboration and the sharing of information and new results before publication. In effect this can mean gaining access to new knowledge years in advance of information becoming generally available through publication. These benefits arise for both individuals and institutions. CSIRO's role in the Global Research Alliance (involving nine of the leading knowledge-intensive organisations from around the world) provides an excellent example of the latter.

Australia's scientific reputation is also important in other ways. For example, it can help to establish Australia as a modern and advanced economy able to provide support for new industries and having a high level of skills. This can help attract foreign investment, especially in areas relating to high value-adding activities.[10] A strong international reputation can also help attract skilled people to Australia, particularly when we are attempting to strengthen or develop our capabilities in fields of national importance.

The international recognition of Australian capability also provides the currency that earns us a place at the international decision-making bodies (such as those developing standards and global responses to global problems) that can have a major impact on our innovation performance.[11] An international reputation is important if Australia is to be an active participant in international scientific activities. This is critical, given the small proportion of global scientific activity for which Australia is responsible. Australia needs a domestic capability, for example, to make use of the data we are able to access from the remote sensing satellites operated by other countries. Striving to go beyond the necessary capability to achieve a high international regard can position Australia to influence the science investment plans of these countries in ways that benefit Australia, while leading to a better overall outcome. More generally, a good scientific reputation can facilitate diplomacy and other international interactions that extend beyond science itself.[12]

[10] A recent US report noted that among the criteria that multinational companies use in determining where to locate their facilities are the quality of research universities and the fraction of national research and development supported by government. (*Rising above the gathering storm*: http://www.nap.edu/catalog/11463.html). Invest Australia certainly recognises this. For example, its regular advertisements in *The Economist* that promote Australia as a target for FDI include statements such as: "…the costs of high quality R&D scientists in Australia are 25 per cent less than in the USA and significantly less than in Europe and Japan." Apart from anything else, this suggests that anyone investing in Australian science, including the government, is getting a bargain.

[11] As a statutory authority, CSIRO can participate in high level inter-government committees and represent Australia in a way that is not open to university or private sector scientists.

[12] Science is apolitical and governments often see science and technology cooperation as a non-controversial way of strengthening relationships.

An indirect benefit of research is that it provides training and develops skills. Training in research exposes people to leading edge science and helps them to develop a critical approach, based on the objective assessment of data and arguments. This can have value outside of science. In a well-operating national innovation system, people move around and take on new roles. This transfers the knowledge and skills they have acquired in a way that formal assessments of knowledge transfer might find difficult to detect but which can have profound impacts on the effective operation of the innovation system.

One important result of the mobility of people having experience with and exposure to research processes, is a general build-up of capability that can help improve the effective operation of the non-research parts of the innovation system.[13]

Business leaders with research training are more likely to appreciate the value, importance and imperative of technical innovation and to integrate the disciplines of innovation within their own operations. Research experience increases their understanding of the options they might use to develop their business. Teachers with research experience may be better able to communicate the excitement and uncertainty of science than people without this experience. People with research experience working in venture capital companies are likely to have skills that will help them better evaluate the technical aspects of the proposals they need to evaluate.

More generally, the capability that research develops is an ability to use skills, knowledge and infrastructure to recognise, create and respond to opportunities and challenges that go beyond the immediate boundaries of past research and present understanding. Equally, researchers with business experience are likely to have a much better understanding of the commercial, legal and other factors that successful innovators have to address – and may even show a higher degree of entrepreneurship.

The importance of a strong domestic science base

Science is a global activity and much of the scientific knowledge developed from research performed overseas becomes available in Australia. Given the size of Australia and of our research effort, it is clear that most of the technology we use will be the result of research performed in other countries. Indeed, the most common form of technological innovation is the purchase of new equipment or facilities. Much of this comes from overseas. Even in these cases however, local innovation in the use of the equipment can create competitive advantage. The development of new business processes making use of purchased computer equipment and software provides an obvious example.

[13] In December 2005 the European Commission invited a group of four experts to give an opinion on how best to improve the EU’s innovation performance. One recommendation was that in the course of each year, 10 per cent of the members of the research community should cross the borders between science, industry and government. *RTD info*, 49, May 2006

Despite the importance of overseas research, a domestic research effort is necessary to keep abreast of what is happening in (and available from) other countries; and to evaluate the significance of this for Australia. However, this does not require an attempt to create the scale of overseas research effort across all areas, which is anyway impossible. Instead, Australia needs to focus its effort into areas where it clearly has, or needs, a strong capability for domestic reasons. This need to specialise provides one reason for setting priorities.

While a strong domestic science base is essential if Australia is to understand, make use of and gain ready access to information produced by researchers working in other countries, it also has a more direct importance. This is because technology development draws much more heavily on research performed in geographic proximity to the technology developing organisation, than it does on research performed at a distance.[14] Empirical evidence for the importance of local research comes from a study which demonstrated that Australian technology has a very high dependence on Australian science, much above what one might expect from the relative contribution of Australian science to the world store of science.[15] The Steve Dowrick review of the economic literature on the evidence on science, research and productivity also concluded that the rate at which small firms innovate depends on their proximity to researchers in the relevant fields.

This dependence on local science may reflect the increasing importance of tacit knowledge in moving from science through technology to innovation.[16] Invention and innovation require an appropriate industrial infrastructure, ready communication between scientific and technological peers in industry and the public sector and an ability to apply and use knowledge. The skills necessary to apply knowledge may be difficult to convey in a written paper. Direct contact between (or the movement of) people is often the best form of technology transfer. Even when this does not occur, transfers between organisations having a similar work culture and sharing common practices that result from a shared education and training culture might be easier than transfer from a different environment.

A strong dependence on the domestic (and local) science base when developing technologies which have potential application anywhere in the world may at first sight be surprising. However, it is not surprising that there are some areas of research important to Australia that researchers overseas are unlikely to address.

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[14] The submission from Griffith University to this Productivity Commission study into public support for science and innovation provides detailed analysis of evidence that proximity between research performers and the users of research outputs is important in achieving impact.
[15] F Narin, M Albert, P Kroll, D Hicks. (CHI Research Inc.) *Inventing our future. The link between Australian patenting and basic science*. http://www.arc.gov.au/publications/arc_pubs/00_02.pdf (The same study also showed that 90 per cent of the scientific research papers cited in Australian-invented US patents issued to private companies had authors from publicly funded organisations in Australia or elsewhere. Moreover, 97 per cent of all Australian scientific research cited in all Australian-invented US patents came from publicly funded institutions.)
[16] This is not to suggest a linear process of innovation. Rather, knowledge transfer tends to be iterative involving multiple actors and many interactions at different times. This complex nature of the process may be one reason why the ease of local contact is so important.

Australia has a unique culture and environment. A high proportion of Australia's plants and animals are found no where else. Some of the factors affecting the general health of our population are peculiar to Australia, reflecting differences in diet, climate and other local factors.[17] Australia's agricultural and mining industries operate under conditions often very different from those found in other countries. Our minerals may have unique physical or chemical characteristics which prevent the transfer of processing techniques from overseas. We are responsible for an area of ocean that exceeds our land mass. Clearly, if science is to make a significant difference to any of these areas it will need to be Australian science.

In considering the need for a strong domestic science base, it is important to include in this base not just a research capacity but also the provision of scientific services. Australian firms would be at a very serious disadvantage if they had to go overseas for the specialised analytical, testing or test bed services that they need to run their business. In fact some countries may limit access to these services for overseas countries, especially when the results of such services are necessary for firms exporting to the country providing them. While it is explored in more detail later it is important to note that in Australia CSIRO plays an important role in developing and providing many of these technical services.

As discussed later, the structure of Australian industry can lead to a market failure because the market for necessary scientific services may be too small to allow a commercial supplier to meet the need at a reasonable cost. In these circumstances there can be an argument for their supply by government research agencies that already have the necessary expertise and facilities, even if used for other purposes. The impact of not providing such services is that firms, and industries dependent on them, might not be able to develop within Australia.

One of the most important reasons for developing a strong domestic science base is that it provides the capability to respond to issues that require technical input, whenever they occur. Especially given Australia's location, size and state of development, it would be inappropriate to expect that whenever a crisis arises it would be possible to draw on expertise from overseas. Moreover, in some circumstances, such as in the case of trade disputes on technical matters (pesticide residue safety levels, or biosecurity matters) there can be conflicts of interests in a reliance on support from other countries. In any case, there is an implied responsibility that Australia contribute to the research necessary to address problems that cross national boundaries, such as climate change, atmospheric pollution, energy security, and so on.

[17] For example, the relative importance of skin cancer and colon cancer within Australia.

Time to impact – incremental and radical innovation

A major scientific discovery can have immediate impact by changing the way scientists and others think about the world as soon as they have become acquainted with the discovery. However, the time that it takes this improved understanding to lead to new technologies, to have a direct economic impact, or to improve environmental and social wellbeing can vary significantly.[18]

Basic research, undertaken primarily to acquire new knowledge, is likely to take longer to have a measurable economic impact than experimental development using existing knowledge to improve already available products, processes or systems.[19] The mechanisms through which basic research outputs exert their influence may be more indirect and often difficult to discern than the route from experimental development to economic impact. And in some cases, developments in technology can leapfrog our scientific understanding.

A change in understanding (eg that DNA rather than proteins provides the basis for inheritance) can have a very broad and very long lasting impact. An output of basic research can make itself felt around the world and create open ended opportunities for technology development and other benefits.

The potential pervasiveness of the impact of basic research and the time it might take to produce concrete benefits makes it difficult to measure the benefit in a quantitative way with high credibility. Not least this is because while the impacts depend on the original discovery, they also make use of a variety of additional inputs, including complementary research outputs. Moreover, scientific discoveries are not usually patentable. This inability to appropriate the benefits can itself make it difficult to quantify them. Apart from anything else, it makes it much more difficult to identify all the groups making use of the discovery.

In contrast to basic research, the output of experimental development may have direct relevance only within the firm that is doing the work. (And in some cases IP rights can help ensure that this is the case even when there is potential for wider application.) However, for this reason it can be relatively easy to measure the direct economic impact of the work, although even here there may be spillover effects, especially if the research is published through patenting or some other means.

Work aimed at producing incremental improvements to existing products or processes is likely to produce an outcome more quickly (and more certainly) than work aimed at developing completely new products, processes or approaches – radical innovation. The reality is that most attempts at major innovation fail and of those that succeed most produce only modest returns[20].

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[18] The Allen Consulting Group's report *The economic impact of cooperative research centres in Australia* (2005) noted that the average time between the foundation of a CRC and the commencement of the economic impacts it studied was 9 years

[19] There are always exceptions. The pharmaceutical industry provides a good example of development often extending over many years (because of mandatory testing requirements) before it can produce a direct financial return.

[20] Attachment 2 includes a discussion of data from Stevens and Burley suggesting that drug companies typically require up to 8 000 starting ideas for every successful new commercial product while across

A relatively small proportion of innovations produces high returns. Work aimed at achieving major changes is inherently more risky in a technical sense than work trying to produce incremental improvements. Moreover, attempts at radical change involve greater commercial and market risks and will normally require very significant non-research investments to convert even a technically successful invention to a commercially successful outcome.

In this context it is worth quoting from Scherer and Harhoff's examination of the size distribution of returns from inventions and innovations attributable to private sector firms and universities.[21] Their study used eight sets of data totalling over 4 000 observations and the authors note:

> *Legislators and senior government leaders are likely to view government technology programs in which half the supported projects fail to yield appreciable returns and only one in 10 succeeds handsomely as a rather poor track record when in fact, by the standards of private sector markets, it is quite normal*.

As discussed in the next section, there are good reasons to expect that the measurable, direct, economic impact of publicly funded research should be less than that of research performed by the business sector, so this conclusion is especially important.

Different forms of research produce impacts according to different timescales and operate within different levels of risk. Any study attempting to measure the impacts of different elements of the research system should take into account the particular roles and responsibilities of the system component and the kinds of research it is performing. This means taking into account the relative importance of different types of research (basic, applied and experimental development) within the organisation. It also requires an understanding of the position that the organisation holds within the innovation system as a whole. Given the focus of the commission's study, this means acknowledging the reasons why the government is providing support for science and innovation, as discussed in Attachment 2.

The innovation system

Innovation involves much more than science, invention and technology. Moreover, no matter how good the science (or the technology) it cannot, by itself, result in innovation. Science creates understanding and produces ideas but these ideas have no external impact until it becomes possible to apply them in a way that creates value.

The innovation system as a complex system

Innovation is a complex and often chaotic process and it is now customary to use the concept of an innovation system in analysing how the process works. The innovation system is the network of institutions, people, relationships, policies and flow of funding that creates the potential to identify the promise of possible changes and that encourages, facilitates or impedes their implementation.

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most other industries the figures is 3 000 starting ideas for a successful project with only 59 per cent of successful commercial launches resulting in a profit to the company.

[21] F.M. Scherer and Dietmar Harhoff, (2000). Technology policy for a world of skew-distributed outcomes. Research Polcy 29: 559-566.

As well as being complex in the general sense of the term, it is likely that an innovation system is complex in the technical sense. A complex system is one the behaviour of which it is impossible to predict or understand from the characteristics of its component parts. The whole is greater than its parts.

In a complex system, the interaction between the parts allows the emergence of behaviour that it is not possible to predict from the behaviour of its isolated components. This emergent behaviour depends upon the nature of the interactions as much as it does upon the character of the parts; and it changes when these interactions change.

Complex systems are inherently non-linear and so may exhibit irreversible transitions between alternative states. They may exhibit self-organisation. All these characteristics mean that complex systems are not amenable to micro-management. While it is important to facilitate interactions between the different components, it can be counterproductive to try to control the nature and frequency of these interactions.

Importance of people

While discussions of the innovation system often emphasise the institutional framework that provides the system's foundations, it is important to recognise that the interactions necessary for successful innovation take place through the people working in those institutions. The culture, attitudes and behaviours of people working within the system, and the changes that take place in these characteristics through the kinds of experience that arise from their interactions, can play a significant role in determining the effectiveness of the system

Innovation is about working to achieve an agreed outcome by using the complementary knowledge, skills, expertise, curiosity, imagination, responsibilities, leadership and other attributes of people, drawing on the resources of different institutions. There is no set route through the system and the obstacles that exist can be quite specific to different sectors or even particular inventions.

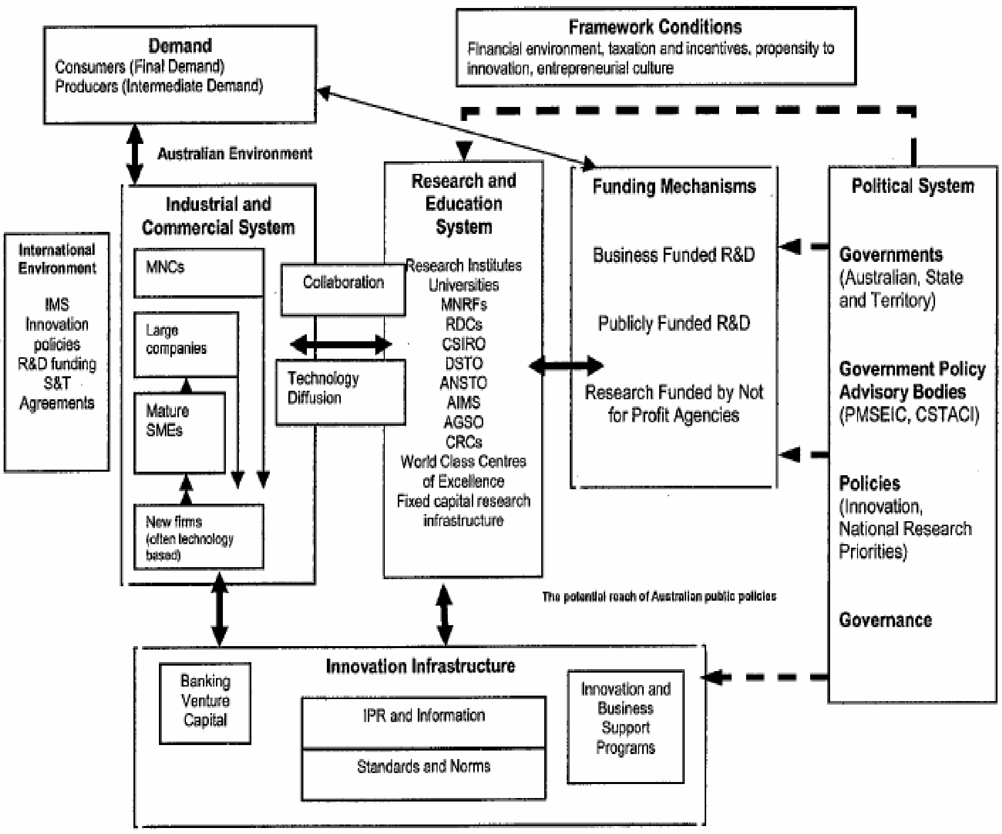
While people drive innovation, it is worth noting that people can also serve to stifle innovation. This can happen for a variety of reasons. Personal attitudes (for example to risk management) or community concerns (for example about the potential safety of nanotechnology or recombinant DNA technology) can impede the translation of scientific discoveries or new technologies into economic outcomes. This means that 'licence to operate' issues can affect the operations of the innovation system. In looking to capture the benefit of public support for science, it is necessary to ensure that the community understands and supports the application of the science.

As well as all the people and organisations involved in the research and science, the innovation system includes players such as consultants, extension service workers, the providers of venture capital and other parts of the financial system, education providers, the legal system dealing with issues such as IP and contract law, trade and marketing institutions, production and process engineers, designers and so on. A country's regulatory environment (including its tax system) can play a very important role, the significance of which can vary from sector to sector.

Technical innovation often involves buying technology, usually embodied in equipment, sometimes in the form of licensing agreements or other arrangements, sometimes through the purchase of consultancy or other services. This means the technological innovation system has to include technology vendors, institutions providing training in the use of technology and aspects of the trading system that can help or hinder the purchase or importation of technology. Depending on the particular technology, there can be workplace relations issues and the arrangements for dealing with these can have a major impact on the success of the innovation.

The dynamic nature of the system

The figure below presents one depiction of Australia's innovation system, taken from the Department of Industry, Tourism and Resources submission to the House of Representatives Science and Innovation Committee inquiry into pathways to technological innovation.[22] To the extent that the focus of this diagram is on the commercial outcomes of innovation, it presents a simplification and does not note the way in which some innovation operates directly through the political and social systems. However, any pictorial description can at best be partial and reflect a static, simplified view.



[22] http://www.aph.gov.au/house/committee/scin/pathways/subs/sub82.pdf

One problem with evaluating the national innovation system, apart from its inherent complexity and that the boundaries of the system can change for different kinds of invention, is that the system is dynamic. There are structural changes as different institutions adopt new roles or responsibilities, become of greater or lesser importance and as new institutions appear; and the policy framework is constantly changing.

The policy framework for the innovation system changes for many reasons. One is that adjustments made for other reasons might have an unanticipated effect on the innovation process. But it is also because the results of past innovation can raise issues and concerns that in themselves lead to changes in policy or approach. Obvious examples come from the debates relating to the use of recombinant DNA technologies, the impact IT developments have had on copyright and patenting legislation, or recent discussions about nanotechnology.

The international dimension

Another complexity is that any innovation system inevitably has an international dimension and international links. There are several reasons for this. In the case of technical innovation, for example, most of the world's research takes place outside Australia and we import most of our technology. The converse of this is that Australia's market is so small that many major Australian inventions will need overseas users to adopt them if they are to become commercially successful.

The ways in which our innovation policy environment differs from that in other countries can play a major part in our ability to attract foreign enterprises to establish here, perform research and development here, or use Australia as a marketing base. In many ways our ability to develop effective partnerships with overseas and multilateral bodies can have a major impact on our domestic system.

The innovation systems of different countries have their own particular structures and may operate in different ways. These differences can have cultural or historical origins, and can reflect matters such as the importance of different industry sectors, the proportion of differently sized firms, trading relationships, the role adopted by government, national governance arrangements, and so on. For example, a major factor in the development of the system in the USA has been the importance of defence research and the defence industries. Defence research and development, underwritten by government, has built a capability that the country has been able to deploy for other purposes. In Australia a major factor has been the relative importance of agricultural and resources industries in our development, our lack of any large firms and our relatively small manufacturing sector which developed under strong protection.

The need for a whole of system approach

Despite these many differences, governments around the world are adopting a whole of system approach to their support for science and innovation. Australia's 'Backing Australia's Ability' group of programs, and the processes used to develop this, provide a prime example of this.

While it is possible to describe the components of the innovation system in great detail, this can be misleading. The system is not a discrete or isolated entity, but a concept, the elements of which exist in a complex environment and which interact with many other groups in all kinds of direct and indirect ways. A high level description of Australia's system, for example, will include the business sector playing various roles. However, the business sector is itself a concept which brings together what in practice is a disparate group of firms, each of which has its own agenda and own problems.

Firms, even those heavily investing in research, or in the development or acquisition of technology, put most of their activities into operations that do not relate at all to the innovation system. Individual firms do not consider their activities as having an impact on the system, or have any concern about what this impact might be.

The operation of the system flows from interactions between its different components. The effectiveness of the system depends critically on the quality of the linkages between its various elements and the removal of any impediments to these linkages. Moreover, for the system to operate well, all its individual components need to be effective. It is not possible to optimise a system by concentrating on only one of its elements. Neither is it possible to improve the effectiveness of the system by reducing the capabilities of any of its components.

Government expectations from research

In developing a framework to evaluate the impact of government support for science, it is important to take into account the reasons why government supplies such support – in effect, to assess the impact against the customer's requirements and expectations.

Differences between business and government investments in research

When a business invests in research and development it intends to appropriate to itself as many of the benefits of the research as it can. The purpose of the research is to create outputs the firm can use to increase its competitiveness, develop market share, grow and increase its profits. Higher profits provide its owners with higher returns. Among other things, this makes it possible to develop a good understanding of the return a firm receives on its investment in research.

When the government invests in CSIRO it does not expect to receive its return from the growth of CSIRO and the receipt of dividends. CSIRO's role is not to internalise the benefits of its research but to maximise them. Moreover, a significant proportion of CSIRO's research will not produce outputs that can result in a direct dollar return to the organisation, although this does not mean they have no impact. And while all business research aims to achieve a single objective, CSIRO research always has multiple objectives and aims at a broad range of impacts beyond its primary purpose.[23]

[23] While business research may have broader impacts these are spillover effects and do not generally form a reason for performing the research.

To put into perspective these differences between business and public research, it is useful to consider justifications for government support of research. Attachment 2 provides a detailed analysis.

Government as a direct customer of research

Government supports some research for the same reasons the private sector invests in research. This occurs when the government itself needs the research outputs to meet its own responsibilities. This is clearly the case when the government is providing the services that will benefit from the research. Defence, meteorology and metrology provide obvious examples, as do some areas of environmental management. Technical regulation can also require research support.

To be effective research performed for government must have an identified customer: there must be an agency that has both the interest and commitment to use the research findings, should the objectives of the research be met. This means that research carried out to improve the provision of government services should be consistent with the priorities and responsibilities of the customer agency and produce results that are within the financial, technical and management capability of the agency to implement. Governments often conduct such research in-house (eg DSTO, the Bureau of Meteorology) or use contract or grant funding mechanisms to align the supported research with their needs.

However, even when government is the direct customer for the research it is supporting, its motive is not profit but social and environmental wellbeing, although there may be cost reductions from efficiency gains.

Government research support going directly to business

Most government funding does not support research necessary to meet the government's own direct needs. Indeed, a significant proportion of government funding goes directly to business to help it perform research that will meet the needs of the business.[24] The resulting increase in competitiveness and growth of these businesses will generate employment, exports and other outcomes that benefit Australia as a whole. Other government funding is supporting research that business will not fund (and usually cannot afford to fund) because its purpose is purely to advance knowledge. As discussed earlier, this basic research is important but its benefits may be difficult to identify in any quantitative way.

Government support for public research directed to economic impact

CSIRO does perform some basic research and research that helps the government meet its responsibilities in areas such as natural resource management and environmental sustainability. However, it also conducts research that aims to have an economic impact. As discussed in Attachment 2, the basic argument for government support for this kind of research is that market failures mean firms invest less in research than would be in the national interest.

[24] In 2006-07, estimated commonwealth support for science and innovation to the business sector is $1 252.5 million.

Difficulty of appropriating research results

Market failure is in part a result of the spillover and second order effects that allow individual firms and groups to benefit from research outputs produced by other organisations. The information that research produces is often available to others (even if it is of a nature that allows for IP protection); and the fact that one firm is using the information by itself does not prevent other firms from using the same information. Because firms are able to free ride on the research performed by others, they are less likely to perform their own research, not least because this might then help their competitors.

High risk of research

A further reason for underinvestment (compared to socially optimal levels) by the private sector is that research is risky. Particularly for small firms having few opportunities to manage this risk, investing in research has the potential to severely damage the business should a major research effort fail. This is an especially important issue for Australia given its relative lack of large firms.

As discussed in Attachment 2, risk is not just a matter of potential technical and commercial failure. It can also relate to the time that might be necessary to achieve an economic benefit from the research output and uncertainty as to who will capture the benefit, as well as to the availability and commitment of the other players in the innovation system necessary to achieve that benefit.

Social values and attitudes can also be important components of the risk faced by technical innovators. A comparison between the development of the biotechnology industries between the USA and Europe can demonstrate this in very clear terms (as can differences between Australian states with respect to genetically modified crops). This means that in the case of radical innovation there can always be a high level of sovereign risk. Governments might react to community unease by passing legislation that affects the value of any technology that might come from the research. Community concerns about nanotechnology or stem cell research provide recent examples.

Individual firms may lack the resources or understanding to manage by themselves the possibility of sovereign risk resulting from community misapprehension or information shortfall. For this reason it can become a major disincentive for investment. This is a further reason why CSIRO's reputation as an independent and disinterested source of scientific advice, respected by the public, is important. By providing information and facilitating debate, CSIRO's communication activities can help reduce this risk and create an environment within which the private sector can make investment decisions more confidently.

Implications of market failure arguments for expected performance

If the government is supporting research because its results are not easily appropriable or because the research is too risky for the private sector (or takes too long to produce an economic return), this has implications for the impacts that publicly supported research might produce.

An inability to appropriate the research results means that it can be very difficult to identify all the beneficiaries of a particular piece of research, the whole range of benefits it has produced, or even how it produced them. (It also means that comparing the patent applications of an industrial research laboratory and a publicly funded research agency is misleading.) Similarly, government support intended to compensate for the high risk of major research projects means that benchmarking publicly supported science against business research outcomes is also misleading.

Government taking a leadership role

A further reason for government support, and one that is very relevant to CSIRO's role, is that the government might want to take a leadership position. The government might foresee a need for which market signals are very weak or do not exist. In some cases this might be because of political or policy uncertainty. For example, the government might recognise the need for improved renewable energy technologies. However, if uncertainty about the policy environment (for example the introduction of a carbon tax and its likely level) means that the private sector will not start work in this area, the government may decide to intervene. (This not only ensures that technology options or technical capabilities are available if they become necessary, the research might also make it cost effective to introduce legislation promoting the use of renewable technologies that otherwise might have had too great an economic cost to be politically viable.)

In other cases it may be that strong market forces are decreasing the diversity of the economy in a way that might cause longer term problems. For example in a resources boom the market can reallocate resources away from the emerging industries that will need to form an essential part of the country's more diverse economic base when the demand for commodities and their prices drop. Relying purely on market signals to focus research into these areas of opportunity might mean that the necessary actions occur too late to be of any use.

Attachment 2 provides a fuller discussion of these issues and presents data on the high failure rates that occur in trying to convert good ideas, through science and technology into successful innovations.

CSIRO's place in Australia's innovation system

Australia's research sector

In considering technical innovation, it becomes possible to recognise a hierarchy of subsystems. The technical innovation system itself includes the complete range of organisations and policies that can play a role in converting research (or knowledge) to useful applications, whether these are commercial or public good outcomes. Within this overall system it can be useful to distinguish a separate science system and then, within this, a research system. While there are clearly overlaps between these (and CSIRO plays as important a role in the science system as it does in the research system), considering them separately can help simplify what otherwise involves very complex interactions. There are important interdependencies between these different systems – but, just as importantly, the linkages within each system are also critical.

Each of these subsystems has to operate effectively if the innovation system as a whole is to perform. One cannot optimise a system by concentrating on only one of its components. It is necessary to address all parts of the system but in particular to pay additional attention to those components that are operating least well – the limiting factors. While research is not always the limiting factor in an innovation system, it plays such a crucial role that it is essential not to underestimate its importance. This is because research generates options that create opportunities for all other parts of the system.

The science system includes a range of institutions and relationships. As well as all research performing bodies, it includes government and private sector organisations and university laboratories that provide non-research scientific services. These include exploration, analytical, identification, testing, calibration, accreditation, test bed and a wide range of consultancy and advisory services. These form an essential part of our overall science and technology infrastructure. They are essential to the provision of health, safety, legal and other services. They can play an important role not just in maintaining industries, but in developing them. For example, exploration carried out by the minerals industry does not count as research under any standard definitions. Despite this it represents a significant investment in scientific services and can, as a spillover effect, advance knowledge and understanding.

The research system is a sub-component of the science system and consists of all the groups that fund, perform and use research, together with the interactions between them. This system is the driver of technical innovation and the main source of radical, breakthrough innovation. The components of the research system include the government and business sectors which fund, perform and use research; and the higher education sector, which performs and uses research.

Each element of the research system has different roles and responsibilities, although there is some overlap. Individual elements of the research system operate in different ways and aim to achieve different kinds of impacts. In doing this they interact, drawing upon their complementary approaches to achieve outcomes that would be beyond the capability of the individual components.

Equally important is that each element of the research system draws upon the knowledge that the other parts create, even though the major flows go along the route from basic research to experimental development.

These interactions between the different elements of the research system are critical for the effective operation of the whole system. Investigator led science, driven by curiosity and investigating the most challenging scientific problems, has a different purpose and will have different impacts from research aimed at improving a particular manufacturing operation. They can appear as two quite different processes operating in different cultures. Nevertheless, even the most focussed experimental development is making use of the knowledge accumulated from the past activities of leading-edge, curiosity-driven research. This knowledge might now be in textbooks and technical manuals rather than scientific papers or interactions with academics, but it is none the less important. Conversely, developments within the scientific instruments industry, for example, may enable scientists to collect data of a kind or quality not previously available and open up new possibilities for research and understanding. In other words, each part of the system is feeding diversity and creating options that other parts of the system can exploit to create novelty and even further options.

The strength and relevance of public sector research has a direct influence on the ability of business to conduct its own research and to improve its performance. Indeed, public expenditure can lead to greater private sector investment, as CSIRO's National Research Flagships have shown. This is because firms that build on the outputs of public sector research can achieve shorter times to market (building on the longer term research performed by government); and firms may benefit from reduced levels of technical risk because the public sector research has reduced technical uncertainty. In addition, firms are able to use public sector facilities that they would not be able to justify constructing for themselves. At the same time, government and higher education research outputs often depend on the capabilities created by business sector research to achieve a market outcome.

The interactions between the different parts of the system are not always direct and only some result from formal collaboration. A researcher in CSIRO citing work conducted by university researchers need not have had direct contact with the university. Information flows through many pathways and there are still many interactions that take place through 'the invisible college'. The availability of information through the internet makes this even more likely and at least has the potential to increase the effectiveness, efficiency and scale of this interchange.

Interdependencies between different elements of the research system mean that an effective system requires balance between its various components. The system has to encompass all varieties of research: short term and long term; high risk and low risk; curiosity driven, investigator led research and experimental development; research in different fields and across different sectors. Achieving the right balance is not easy but a complete system that includes all varieties of research provides the best means of retaining and developing the capability that maintains preparedness.[25]

[25] While it is convenient to write about balance between the different components, it is important to understand that there is no single equilibrium point. The respective size of the different components of the system can depend on policy objectives; the existence, structure and responsiveness of an

In an uncertain world, this ability to keep open Australia's options for action and to create new options has a value beyond the direct impact of the research itself.

Roles of the research system components

A simple, high level analysis can serve to identify some of the complementarities between the different elements of the research system and demonstrate their interdependence.

In 2002-03, the different sectors within the research system accounted for the following proportions of Australia's Gross Expenditure on Research and Development (GERD).[26]

Business	48.8%
Higher education	28.0%
Government	20.3%
Private non-profit	2.9%

The sectors differ not only in terms of their size but also in terms of the type of research they perform. The breakdown of activity for GERD as a whole was:

Experimental development	38.6%
Applied Research	35.7%
Strategic basic research	15.5%
Pure basic research	10.1%

The table below shows the proportion of research expenditure in different sectors allocated to different types of research activity.[27] It also includes for comparison the equivalent breakdown for CSIRO's research activity in 2004-05.[28]

	Pure basic research	Strategic basic research	Applied research	Experimental development
Business sector	0.8%	5.8%	25.8%	67.6%
Commonwealth government	6.5%	30.8%	45%	17.8%
Higher education	28.4%	23.4%	40.6%	7.6%
CSIRO	*5.5%*	*38.1%*	*46.9%*	*9.5%*

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appropriate industrial infrastructure; the effectiveness of links between the research system and industry; market issues, and so on..

[26] ABS 8112.0 Research and Experimental Development, all sector summary

[27] Calculated from ABS 8112.0 2002-03

[28] The CSIRO figures mask considerable variation between the organisation's divisions and facilities. For example, 100 per cent of the research of the Australia Telescope National Facility fell into the pure basic research category; 73 per cent of Marine Research activity was strategic basic research; 85 per cent of the Energy Technology division's research was applied research; and 23.3 per cent of the Textile and Fibre Technology division's activity was experimental development.

Overall, the higher education sector accounted for 78.6 per cent of Australia's expenditure on pure basic research, while the business sector accounted for 85.5% of Australia's expenditure on experimental development.[29]

There are also clear differences between the sectors in terms of the socioeconomic objective of the research they perform. Overall, 63.1% of Australia's research expenditure falls into the 'economic development' category. Not surprisingly, however, 90% of business sector expenditure falls into this category.

A fact of particular importance for the commission's study is that only 54.6% of the commonwealth government's research expenditure had 'economic development' as its primary aim. The equivalent figure for the higher education sector is 29%. This is not surprising, given the reasons government provides supports for research, but it does have important implications for the kinds of impact this research should produce.

Of the government sector research directed towards economic development, 28% went towards plant production and primary products; 21% towards animal production and primary products; and 17% towards manufacturing. In considering these figures it is important to recognise that the structure of the primary industries (many, often small enterprises producing the same commodities) provides strong arguments for government performance of research; but at the same time this structure can make it difficult to measure the direct impact of the research in the tight ways sometimes possible for research supporting manufacturing.[30]

Government sector research not directed to economic development targets the environment (20%), society (12%) and defence (11%), with 2% going to 'non-oriented' research. The non-economic development research of the higher education sector targets society (43%); non-oriented research (21%); and the environment, (6%). The major subdivision within society was health, accounting for 28% of total R&D expenditure.

Approaches to the management of research

One consequence of different parts of the research system playing different roles is that they operate in different ways. This is especially evident in the way that they plan, manage and evaluate their research projects. While the approaches used by separate components of the system may be appropriate, given what that part of the system is trying to achieve, they operate in quite diverse ways. (And any one sector might use a variety of approaches.) As a result, the nature and level of impact they achieve can vary significantly, as can the flexibility with which they are able to respond to changes in their operating environment. To illustrate this, it is useful to consider as the extreme cases curiosity led research in universities and experimental development in business.

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[29] These and other figures in this section are taken from the Australian Bureau of Statistics, *2006 Yearbook of Australia*.

[30] A possible exception to this difficulty of accurately measuring quantitative impact in the agricultural area is where there has been a close and long term collaborative arrangement. CSIRO's work for the cotton industry provides one example, although here there is also a relatively small number of growers, which also helps in the collection and verification of data.

Universities

Universities have been performing an increasing proportion of Australia's research and research is an essential part of their operations. However their most important role remains that of higher education and skills development. Their research activities play an essential role in supporting this broader educational function of developing human capital as well as having more direct impacts.

In universities research is often investigator led, with scientists seeking funding from external funding agencies. The research topic often flows from scientific developments of interest to the investigator and the purpose of the research is to address exciting and challenging scientific problems. The greater the resulting leap in understanding, the more successful will be the research. While the investigator might have potential applications in mind, these may be longer term and often rather general. It would be rare for potential users of the research outputs to play a role in planning the research or in setting its parameters.

The funding agencies decide whether or not to provide funding using their own criteria and independently of any research strategy set by the host institution. While there is a very competitive application process, ongoing research management (as distinct from financial management) is largely a matter for the investigator. This means that the management of each project takes place in isolation from the management of similar or related projects.

If the research does not progress as expected, or external factors mean that it has become less relevant, there is no way to redeploy funds to research assessed as likely to produce a better outcome. Instead, the researchers may change the direction of their research to areas that they believe may offer greater promise. Evaluation of the research normally takes place at the conclusion of the project and sometimes only through a self assessment report and a list of outputs that the researcher provides to the funding agency. In fact the real assessment of the quality and significance of the research takes place through the peer reviewed publication process, which has nothing to do with the funding agency or the host institution.

Application of university investigator-led research depends on organisations outside the university becoming aware of the research or on the university informing them of its practical significance. The approach is usually one of technology push and the potential users of the research do not play a direct role in managing the research. In many cases the first detailed consideration of path to market issues takes place when the researcher alerts the university technology transfer company to the possible commercial potential of the research.

This approach makes sense for much basic research which aims to produce advances in knowledge. Direct commercial significance may be a serendipitous outcome but it is not the primary purpose of such research.

Business sector

Business sector research will usually be part of an overall technology development strategy which is itself integral to the firm's business development strategy. All decisions are made internally and in the context of an holistic investment strategy. The management processes and the mechanisms and criteria for evaluating the research are accordingly different from those in universities.

While a research proposal may originate as a bright idea from an individual, its development will normally involve the participation of non-research staff. Funding decisions will depend on the relevance of the project to the business, its practicality and potential impact on business performance.[31] The intention is not to achieve a great leap in understanding but to produce a useful output that the business can use. Breakthrough developments will be of no use if the business does not have the capacity to use them. The research output has to match the requirements set by the business. There is no opportunity to follow-up unexpected findings that look interesting, unless they relate to the solution the business is seeking. Moreover, it will often be necessary to conduct the research according to very tight deadlines set by factors external to the research process.

Because the breadth of research expertise available within a firm is unlikely to be large, the range of solutions that business is able to consider may be small – unless it decides to outsource the research. However this requires an understanding of the range of options that might be available to address the identified problem, knowledge of where the necessary expertise resides and a willingness to approach a service provider with commercially sensitive information while losing management control of the research project.

A business will normally have a process for the ongoing monitoring of its research against criteria which relate primary to its purpose, not the quality of its underlying science. Similarly, a business will normally manage its research projects as a single portfolio and will shift resources between them as necessary. As soon as it becomes clear that a project will not achieve what the business wants, no matter how interesting the research path might otherwise be, the project will stop.

Path to application issues are not usually a matter of concern for business-performed research because the research is responding to a clearly defined market need. The research is market pull and the customer for the research is the business that is funding (often with government support) and performing the research. There are no alternative paths to market and the intention is to capture within the firm all the benefits of the research. However, the business may well have the production engineers and others who will play a role in converting the research output to commercial value participating in the in the research management processes. Speed to application is of the utmost importance. In the case of research aimed at developing consumer goods, for example, marketers and market survey data may play a significant role in steering the research. .

[31] Large firms may invest in longer-term more open ended research than described here but Australia lacks the very large firms that have the research capability and scale necessary to do this.

CSIRO

CSIRO's role within the research system is unique and its research planning and management practices reflect this. The factors that differentiate CSIRO are many. For example, no other organisation has the same set of statutory responsibilities or government links. (Among other things, this provides a more direct path to application for research that has impact by helping to inform policy development.)

Many (perhaps most) research performing organisations have other, and equally or more important, non-research functions. Many other government research agencies (eg ANSTO, the Bureau of Meteorology) have functions which go beyond research and in some cases their research is to support the organisation's primary responsibilities – they are both the research performer and the user of their own research outputs.

That the primary function of CSIRO is to carry out scientific research for the benefit of Australia is one of the factors distinguishing it from most other bodies conducting research. Other organisations have different operational methods and approaches, stemming from their different purpose and functions. As discussed later, in many ways CSIRO's unique role in the system stems from its scale, diversity and institutional funding arrangements. Perhaps most importantly, it is a single enterprise and is able to plan and manage its research as a single portfolio.

Because researchers within CSIRO have research as their primary responsibility, they do not have competing activities such as teaching. Moreover, their administrative, marketing or managerial responsibilities relate to research, even when this is in the context of the broader national innovation system, going beyond the immediate confines of science. This is especially important given that CSIRO is able to plan and manage its research portfolio at an enterprise level. This also helps CSIRO develop large scale, multidisciplinary research in a way that is not open to any other Australian organisation.

Path to impact issues receive attention during the research planning phase and potential users of the research outputs may play a role along with other stakeholders in identifying the problems that CSIRO choses to address. Stakeholders are able to contribute not just to the nature of individual projects but to the research strategy of the organisation. Research planning is strategic and involves broad consultation that would be inappropriate for a business looking after its own interests. Moreover, by operating on an enterprise basis but including both top down and bottom-up processes, the organisation is able to draw upon the creativity and discipline breadth of all its scientists.

A later section of this submission provides details of CSIRO's research management processes. These differ from those of universities and business in many important ways. The focus of CSIRO's research management processes is on impact and relevance to Australia – and in general not on scientific opportunities or on problems particular to individual firms. Moreover, the purpose of the management processes is to maximise the total return, not just the financial return. They recognise that any research can have multiple outcomes and the economic impacts are not always the most important.

Research management within CSIRO involves continuous monitoring against agreed criteria and operates on a portfolio basis. Criteria relate to both the excellence of the science and the impact the project aims to achieve. This allows the organisation to remain flexible. If a project is not going to meet its agreed objectives it is possible to redeploy resources to those areas in which they will have most effect. Just as importantly, active management of research on a portfolio basis makes it possible to direct additional resources to a project when this becomes necessary, or to reconfigure a project to take advantage of external developments.

Because of the way it works to achieve impact for Australia, CSIRO's research management practices can involve the direct participation of outside parties. For example, CSIRO has placed some of its Water for a Healthy Country Flagship projects under external management because this was where the most relevant expertise was available and outsourcing in this way would facilitate the adoption of their research results.

Changes in the research system

Over the last 20 or so years there have been some major changes in the structure and composition of Australia's research system. These reflect the fact that Australia's innovation system has become larger and more complex, with a greater diversity of players. A significantly increased proportion of national research effort is now taking place in industry, while a large increase in the number of universities means that the higher education sector performs a greater proportion of national research effort.

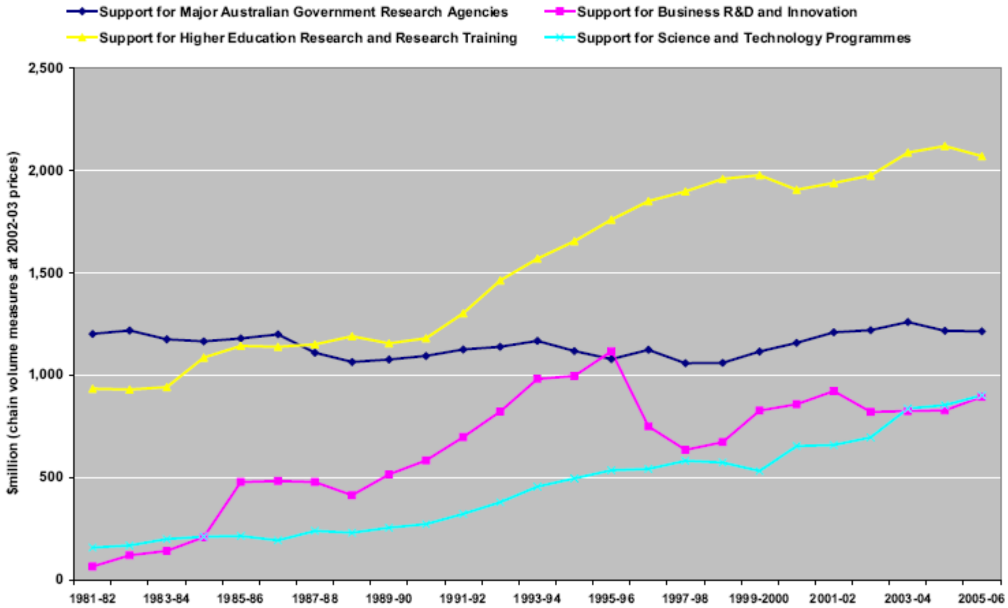
In 1978-79, publicly funded research agencies (of which CSIRO is by far the largest) employed 26 per cent of the total human resources devoted to research in Australia. The higher education sector employed 39 per cent and the business sector 19.8 per cent. By 2002-03, the figures for publicly funded research agencies had fallen to 9.5 per cent, while the figure for higher education had risen to 46.4 per cent and for business to 33.3 per cent.

In terms of expenditure, in 1978-79 publicly funded research agencies accounted for 30.5 per cent of Australia's Gross Expenditure on Research and Development (GERD), the higher education sector 30.8 per cent and business 23.3 per cent. By 2002-03 these figures were 11.9 per cent for publicly funded research agencies, 30.8 per cent for higher education and 51.2 per cent for business.

The figure below shows recent trends graphically, taken from *Australian Science and Technology at a Glance 2005*.

Changes in the proportional distribution of resources between different elements of the research system can take place quite quickly, as shown by the figure. Such changes allow a rapid response to perceived deficiencies in the system. Similarly, it is possible to make fairly rapid changes through, for example the introduction of performance measures – such as number of patent applications. However, because of the long lags that can exist between the performance of research and its impacts, this also means that the rapid changes in the allocation of funds or in agreed performance measures does not necessarily produce rapid changes in the system's performance. Moreover, any unintended consequences or distortions of the system that result from the reallocation can also take time to demonstrate themselves.

Australian government support for science and innovation in chain volume measures (at 2002-03 prices) – by main component for 1981-82 to 2005-06.



Source: DEST, derived from Science and Innovation Budget Information (1981-82 to 2005-06).

Along with these broad changes in the proportional distribution of expenditure shown in the figure, there have been some more subtle changes. In particular, the number and diversity of players has increased with the development of new structures and the more frequent use of older forms of collaboration vehicles. These include cooperative research centres, joint ventures, spin-off companies and centres of excellence. In addition, a wide range of less formal arrangements has arisen from a growing recognition of the importance of collaboration. Examples include memoranda of understanding, joint applications for funding, joint appointments, and so on. As a result of these arrangements, it can sometimes be difficult to draw a boundary between one part of the research system and another.

One consequence of these changes within the research system is that the formerly distinct roles of the different components of the systems have become less clear. For example, the focus of universities on teaching and promoting Australia's wellbeing through the movement of highly educated, skilled people out into the Australian workforce has lessened. Performance measures based on the direct economic impact of their research, or the number of collaborative arrangements they have which provide funding support, take attention away from their primary role. This raises interesting questions as to the extent to which their effectiveness in contributing to Australia's educational outcomes has lessened; and whether they have adapted their research management and overall governance arrangements to the new roles they are taking on.

As well as partnerships within the research system, a more mature understanding of innovation has led to increasing levels of cooperation between research performing bodies and the non-research parts of the innovation system. This simply reflects the better understanding that to convert research outputs to innovations requires the cooperation and coordination of a range of players beyond the research system.

A consequence of these changes is that despite increased collaboration and the strengthening of relationships within the innovation system, there is now a greater level of competition within the research system. Moreover, as expenditure has increased, the government has started to play a more direct role in the operations of the system, for example through the development of national research priorities and through paying greater attention to research investment processes (as with the current work on the Research Quality Framework) and performance indicators. In particular, there has been a major trend towards the use of output and outcome indicators.

One effect of this increased competition for research funds is that all parts of the innovation system are adopting new business models in response to the pressures they face. At first sight this has the potential to increase the level of impact that research is having because all research performing bodies are servicing a greater variety of customers, some with a sophisticated understanding of what they need. However, as competition for funding increased, universities and others started competing opportunistically for industry dollars and for scientific service work that previously they would not have identified as a core activity. As a result, competition for funding is forcing some parts of the innovation system to develop converging roles rather than to develop complementary specialisations. One danger with this is that it can reduce impact (certainly in terms of developing infrastructure and capability). This is because of the potential it creates to dissipate effort rather than to build up specialised critical mass.

This increase in competition is not just domestic. It is commonplace to observe that capital and labour are increasingly (and quickly) mobile and that capital transfer does not always relate to local performance but can be part of a broader political or trade agenda. (For example, large multinationals may move their research facilities to their home country, no matter how well their regional laboratories perform, or to countries still having high tariff barriers.)

Large firms are comfortable performing the separate parts of their production process in different countries. They are increasingly outsourcing research, as well as manufacturing activities, to lower cost countries such as India and China. These countries are rapidly expanding their skills and research base and have very large markets.[32] However, other countries are also taking a more aggressive stance with respect to their research infrastructure. The European Union, for example, has set itself a target of spending three per cent of its GDP on research and development; and has developed a 'technology platform' concept (involving a scale of operation much bigger than that of CSIRO's National Research Flagships) that has the participation of major multinational companies.

[32] They are now sources of cheap skilled labour, while formerly they were seen as sources of cheap unskilled labour.

These global developments have the potential to impact on the Australian research system (and on our industrial competitiveness and society) in several ways. They create the imperative to differentiate and develop niche areas of specialisation; they highlight issues of scale and the need for critical mass to maintain relevance and to keep abreast (if not ahead) of overseas developments; but they also create direct competition as rapid expansion creates a demand for skilled, often highly mobile, scientists.

Deficiencies within Australia's research sector

An effective research system needs many players operating in different ways and performing between them the whole range of research activity from basic to experimental development. Diversity produces capability and increased opportunities. One reason this is important is that innovative companies use a broader range of sources for new product and process ideas than less innovative companies: an average of 3.3 sources used for each project compared with 2.0.[33]

In examining the structure of Australia's research system, it is necessary to recognise that, like the innovation system overall, it reflects a complex of geographical, historical, cultural political and economic factors. Factors that have been particularly influential include our geographical remoteness, our relatively small domestic market, and the important roles that agriculture and our mineral resources have played, and continue to play, in our economic development, and an absence of large firms. Our federal structure has also had an influence that continues. For example, competition between the states for the location of large facilities can bring into the decision making processes factors other than national interest and has the potential to lead to unnecessary duplication, a less than optimal location for an important research facility, or a dispersion of effort.

The table below (using data from 1999) shows the proportion of a country's total research effort conducted by firms of different size.[34] It demonstrates that a country's largest firms tend to account for the greatest proportion of its business research effort.

Number of employees	***Fewer than 100***	***100 – 499***	***500 – 999***	***More than 1000***
Australia	29.2	20.7	12.3	37.8
Canada	16.8	15.8	10.1	57.4
USA	10.4	8.3	3.8	77.5
Korea	4.1	8.8	8.2	78.9

Australia is unusual in the high proportion of its research conducted by firms having fewer than 100 employees. This proportion is higher than for any other OECD country, apart from Iceland. One explanation for this could be that the commitment of Australian SMEs to research is greater than that of equivalent businesses in other OECD countries. However, a more likely explanation is that these figures do no more than reflect the small number of large firms in Australia and the increased relative importance this gives to the smaller firms.

[33] D Grady et al *Unlocking Innovation* McKinsey & Company 1993
[34] Figures taken from OECD, STI Scoreboard, 2001

In the USA, firms having more than 10 000 employees account for 55 per cent of industrial research. This concentration of business research effort in larger firms is not surprising, given the earlier discussion of the risks of innovation and the need to manage this using a portfolio approach.

Research requires highly skilled and specialised staff, expensive equipment and facilities, and a level of financial resources sufficient to apply the research results as well as to conduct the research. Moreover, research involves risk – direct technical risk but also commercial and market risk. Even if the research has a successful technical outcome, it need not result in commercial success. A competitor might get there first, or the market might not have the anticipated interest. Larger firms are likely to have a greater capacity to manage the risk than smaller firms. At any one time a large firm can have a broad portfolio of projects, some of which will be successful and compensate for those that are not.

Some simple calculations can show the difficulties a small firm can experience in conducting research. Consider a high R&D intensity firm that spends (a very high) ten per cent of its turnover on R&D. Such a firm might have ten per cent of its employees working on R&D. Of these, 80 per cent are likely to work at the development end of the research spectrum. For a firm with 200 employees, this would mean 20 R&D staff, of which four would be in research and 16 in development. A firm operating in a low R&D intensity industry, spending one per cent of turnover on research and development, would need 2 000 employees to maintain four research personnel and 16 employed in development. Yet having fewer than four employees working in research is unlikely to be viable.

The significance of this kind of analysis becomes apparent if one compares an innovation system to an ecosystem. Using this analogy, the research system has a number of niches that need filling. One of these relates to the performance of strategic basic research. This aims to acquire knowledge in specified broad areas in the expectation of useful discoveries. It is the research that creates opportunities, rather than responds to them.

Because it does not have a clear focus on a specific practical objective (although it is aiming at a clearly defined, if generalised, outcome), strategic basic research is generally longer term and part of a broader research strategy. This strategy will have a project portfolio that encompasses applied research and experimental development. In many countries, large corporate laboratories occupy this niche. Small firms simply do not have the resources to conduct such research themselves, even though they need to draw upon its results for their more specific projects. Because Australia does not have the very large firms with their large corporate laboratories, the government sector now occupies this niche.[35]

[35] Private sector firms may support research which they consider 'strategic' in terms of their own product development timeline. However, this will typically have a three year time span and be of a nature that scientists in public sector agencies would regard as tactical or incremental.

The predominantly small size of Australian firms compared to that of their overseas counterparts subjects Australian firms to greater financial constraints in funding research. As mentioned in the discussion of risk, one reason for this is the inability of small firms to mange risk by working with a portfolio of projects. This is especially so given that the trend towards shorter product cycles means that a more concentrated research effort is necessary to keep ahead of competitors. A more concentrated research effort requires a greater number of people and better access to more sophisticated facilities and equipment. However, small size limits the degree of specialisation in a firm’s staff and can influence the kinds of facilities they have available. Business can overcome these kinds of impediments by using the services of public sector research agencies. However, firms may even lack the expertise that would allow them to identify which of their problems might be susceptible to a research solution. This again relates to the management and other cultures within the firm and creates a niche that government research agencies need to fill.

An analysis of why the Australian government funds and performs a greater proportion of the national research effort than the government of some other countries becomes even more compelling when one considers the important role still played by agriculture in Australia’s economy. The issue is not just that each farm employs relatively few people and lacks the capability to conduct its own research; it is also that the outputs of different farms may be identical and all the producers of a given crop may be able to benefit from research that improves the performance or quality of that crop. As well as being an important factor in the development of Australia’s research system this has enabled a research funding system based on collecting a levy from producers.

CSIRO's unique role in the national research and innovation systems

CSIRO plays a unique role in Australia's research system and within the broader innovation system. This uniqueness stems in part from its status as a statutory authority, its scale, its diversity, its funding and the way in which it plans, manages and evaluates its research. In fulfilling this role over the last 80 years, CSIRO has developed its reputation as an independent and credible source of advice to government and, more generally, to the public.[36]

CSIRO's reputation as a trusted source of advice is not only an important component of its intangible capital; it also provides a foundation from which to deliver impact from science – as shown by the success of *CSIRO's Total Wellbeing Diet*. [37]

The *Science and Industry Research Act 1949* sets out CSIRO's functions (Attachment 1). CSIRO's primary functions are to perform research and to facilitate the application of research to assist Australian industry, further the interests of the Australian community and help achieve national objectives.[38] This means CSIRO's focus is on strategic research that provides solutions, supports scientific and research services, and develops technology. The organisation delivers science solutions direct to Australian industry and communities while building the science base that allows it to do this. However, the Act also identifies functions other than research and its application. These include the provision of scientific services, international liaison, training, and the communication of scientific information.

Central to CSIRO's strategy is to concentrate its effort on those activities and functions that no other organisation can do better. If CSIRO is not the best organisation to perform necessary research, it will draw on world class facilities and expertise where they already exist in other Australian organisations. In other words, the organisation adopts a systems approach, recognising that the success of CSIRO in meeting the mandate government has given it depends on many other players outside CSIRO's control. At the most basic level, while CSIRO performs research, others will need to make significant financial and other investments to convert the research outputs into innovations. For this reason CSIRO's strategies and approach do not leave the uptake of research to chance: they strive to create the networks, support and other conditions that facilitate and encourage this investment. An important factor here is that other parts of the innovation system, both domestic and global, know they can depend on what CSIRO delivers.

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[36] A 2003 survey by Biotechnology Australia found that CSIRO remained the top information source respondents felt likely to provide reliable information about gene technology (84%), followed by schools and universities (81%) and then scientists (73%). http://www.biotechnology.gov.au/assets/documents/bainternet/MB2003Final20050713094939%2Epdf

[37] While this is a topical example, it is worth remembering that CSIRO scientists and CSIRO Publishing are responsible for many other popular books (and other publications) that provide the general public with easy access to high quality scientific information

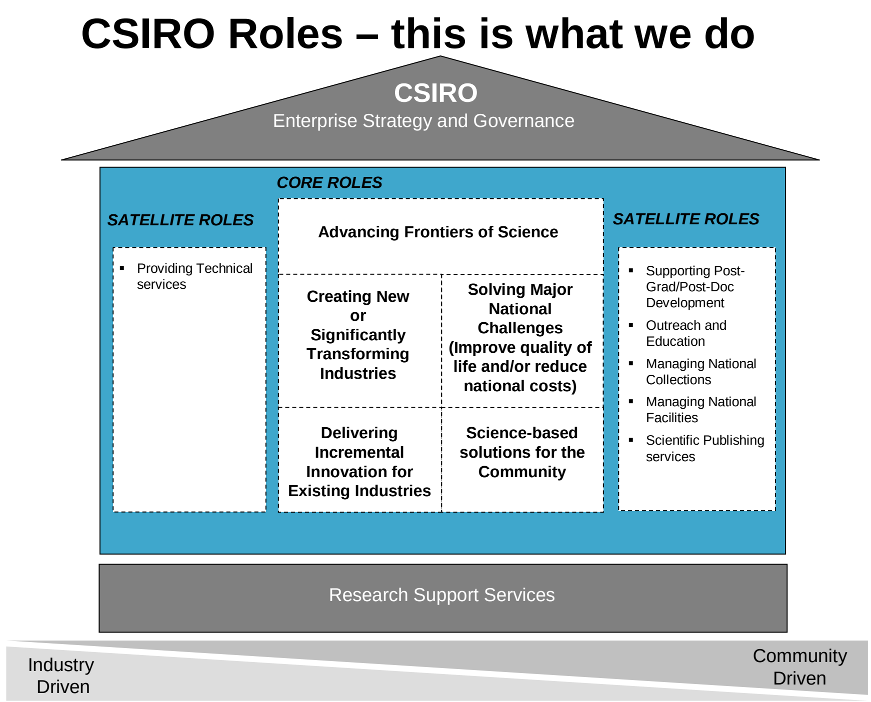
[38] An important secondary function is to encourage or facilitate the application or utilisation of the results of any scientific research performed by bodies other than CSIRO.

The 'role house' model

In responding to the changes that have taken place over recent years, an important part of CSIRO's strategy has been to clarify its role within Australia's innovation system. By clearly defining the organisation's purpose it becomes possible to develop the governance and research management processes that best meet this purpose. Clearly defining the role which CSIRO occupies also helps other organisations understand CSIRO's place in the overall system and provides a basis for developing complementary relationships, reducing duplication of effort and improving accountability.

The role house model provides a convenient way of looking at CSIRO's functions.

The model shows CSIRO's core roles at the centre of the diagram, surrounded by satellite roles. The enabling functions make up the 'roof' and 'floor' of the house, highlighting the support and guidance they provide to the other roles. The house also illustrates the continuum between industry driven activities (left side of the house) and community driven activities (right side of the house).



The industry driven / community driven continuum illustrates that while all of CSIRO's activities ultimately deliver benefits for the whole of Australia, some activities respond more directly to industry needs and others to community needs. The dashed lines within the house signify the integration and interdependence between the roles. None of the roles can exist in isolation – there are linkages between each of them. No sharp boundaries exist between roles, and no core role is separable. Within the core roles, time horizons correlate with vertical position within the house. In other words, 'Advancing Frontiers of Science' has a long-term time horizon while 'Delivering Incremental Innovation for Existing Industries' has a much nearer time horizon.

The satellite roles shown in the model clearly demonstrate CSIRO’s importance not just within Australia’s research system but also within the broader science system through activities such as the provision of technical services and the management of national scientific infrastructure.

Attachment 3 provides examples of the science associated with the different roles identified in the model and indicates the kind of impact that these different roles aim to produce.

Because most people see CSIRO purely as a research organisation, it is worth noting that one of CSIRO’s statutory functions is to ‘carry out services and make available facilities, in relation to science’. Maintaining and making available national collections and managing national facilities help meet this responsibility. In addition to this, however, CSIRO offers around 50 specialised technical and analytical services to industry and other researchers.

These scientific services form an essential part of Australia’s science, technology and innovation infrastructure. Without them firms in many industries would find it difficult to operate, to meet domestic and international standards, or to be sure they were operating within the regulatory framework set by governments. While the model identifies these as satellite roles, they are none the less important for that.

Despite its value, the role house model has some limitations. People are at CSIRO's core, yet the house model does not adequately emphasise the importance of scientists and staff in delivering impact to Australia, nor does it highlight the importance of collaboration with external parties. The diagram may also give a false impression of a static and unchanging CSIRO and it does not seek to represent the relative size of each of the roles within CSIRO. This can be quite misleading. For example, over the past three years CSIRO has made very significant shifts in the proportion of its investments going to different roles.

Because it is built around outputs and outcomes, the model cannot show the way in which CSIRO processes play a national role. As discussed later, CSIRO can have impact not just through the outputs of its research, but also through the planning processes it applies to identify and develop some of the major national challenges it will address.

Nonetheless, the house diagram is a simple tool that reflects the roles and purpose of CSIRO. People inside CSIRO and external to the organisation have found the model helpful and it provides a useful means of mapping changes taking place as CSIRO implements its strategic plan.

Importance of scale and scope

Two of the characteristics that most distinguish CSIRO from other parts of Australia’s research system are its scale and its internal diversity. These help define its niche in the overall innovation system.

CSIRO is large, being Australia's largest research organisation. As such, CSIRO accounts for a very significant proportion of Australia's total research effort. Its projected total revenue is $970 million for 2006-07. For comparison, Australia' total expenditure on research and development in 2002-03 (the latest year for which figures are available) was $12 249 million.[39] As previously mentioned, CSIRO receives around 10 per cent of total commonwealth support for science and innovation in the form of its direct appropriation.

The organisation employs over 6 500 staff in 17 research divisions and two joint ventures located across 57 sites throughout Australia and overseas.[40] In addition, at any one time the organisation will be host to a varying but large number of visitors (usually over 2 000) making use of CSIRO's facilities, and national collections, participating in joint research projects or generally making use of the vast and diverse expertise available within the organisation. These visitors include hosted students, CSIRO Fellows, visiting scientists, contractors and other, miscellaneous groups.

Over 60 per cent of CSIRO staff hold university degrees, with more than 2 000 having doctorates and 470 having masters' degrees. The table below provides further details on staffing and in particular shows the importance of CSIRO in providing post-doctoral employment opportunities and training for postgraduates.

Staff Numbers and Composition (June 30)	**2003**	**2004**	**2005**	**2006**
Proportion of Research Staff*	66%	66%	65%	65%
CSIRO PostDocs	207	259	282	290
Contribution to Research Training	**2003 (June 30)**	**2004 (June 30)**	**2005 (June 30)**	**2006 (June 30)**
Sponsored PostGrads	194	235	245	277
Supervised PostGrads	535	566	513	423

* Includes Research Scientist / Engineer, Research Projects, Research Management, Research Consultant functional Classifications

[39] While large in an Australian context, it is worth remembering that there are a number of overseas firms that individually spend more on research and development than does the whole of Australia.

[40] Apart from the benefits that arise from its activities, regions can benefit directly from having a CSIRO facility. Especially in rural areas, a CSIRO facility can make a significant contribution to the local economy by providing employment and through local purchasing activity. In some cases (eg radio telescopes) the facility can be a tourist attraction, helping generate further economic activity. Even when this is not the case, visiting researchers help the local economy and the presence of a facility can help provide or attract infrastructure that might not otherwise be available to the local community. There are other benefits, perhaps more indirect. Having a pool of highly trained research scientists can add to the richness of the cultural and social networks as well as provide a set of expertise that would not otherwise be available. Moreover, and despite the increasing effectiveness of electronic communications, local knowledge can be important and local presence can help technology transfer. Businesses near to a major research facility are likely to have a better knowledge of the facility than other businesses and may find it easier to approach the researchers for help. Collaboration is often easier or more likely when the collaborating organisations are close to each other.

Scale provides visibility, both in Australia and overseas. People know that CSIRO is there and it will often be a first point of contact for people having a scientific problem. This makes sense because CSIRO's facilities, equipment, collections and expertise form a significant part of the national science and technology infrastructure. The organisation designs, constructs, manages and operates these facilities on behalf of the scientific and broader community, in Australia and overseas.

Scale is also important in the development of linkages within the domestic innovation system. In looking to initiate research partnerships, other players in the innovation system (domestic or foreign) turn naturally to CSIRO because of its visibility – a consequence of its size, the quality of its research and the distribution of its facilities across all states and territories. The relationships that CSIRO develops through its visibility and ongoing work allow it to perform a gatekeeper and brokerage role between other organisations and firms, even when CSIRO itself is not the most appropriate partner. There can also be an effect at the level of individuals. CSIRO's scale when combined with its reputation for excellent science can help attract talent not just into CSIRO itself, but into Australia more generally.

Complementing the scale of CSIRO's operations is that it is one of the most diverse research agencies in the world, covering most scientific fields and using a very broad range of research techniques. As well as working in most fields of natural science and engineering, CSIRO also employs researchers in the social sciences. This is especially the case when contributions from the social sciences provide the means through which the natural sciences can benefit Australia. Some areas of natural resource management provide a good example, as do some other public good areas such as preventative health.

Being able to draw upon such a diverse range of expertise within a single organisation provides a significant competitive advantage that is central to CSIRO's ability to design and plan research strategies that address national problems.

In considering how to respond to a particular issue, it is natural for research performing agencies to start with solutions that fall within their competence. As a result, the range of expertise and facilities available within an organisation can limit the possible solutions that it can identify. This is as true for organisations as it is for individual scientists. Peter Medawar, for example, has noted that:

> I learned from my own early days in research that if one lacks adequate equipment - e.g. an ultracentrifuge or facilities for radioactive labelling and counting - then some internal censorship of unknown circuitry prevents one having ideas of the kind that could only be evaluated by means of such equipment. Money can't buy ideas, that's for sure, but lack of it can prevent one having them.[41]

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[41] P. Medawar, 'The cost-benefit analysis of pure research', in *The Threat and the Glory: Reflections on Science and Scientists*, Oxford University Press, 1990, p. 220.

CSIRO's breadth of expertise means that it is able to take a very broad view in considering how best to tackle an issue. The organisation can bring together people having different skills and expertise (including social scientists and economists) from within the organisation to develop a truly multidisciplinary approach. Such an approach clearly has benefits from a scientific perspective because the major breakthroughs increasingly occur where different disciplines intersect. However, a multidisciplinary approach has broader national implications. The complexity of the issues that face society is mounting all the time. The complex 'wicked problems' that can arise, for example, in trying to develop a safer, happier or healthier society will often require complex solutions.

Achieving these usually involve multiple stakeholders, multiple, intricate social interactions, and the bringing together of a wide range of technical skills and expertise from a range of disciplines. The transactions costs in trying to implement this approach across many different organisations, each with its own culture, process, procedures and objectives can be considerable. In many cases CSIRO can achieve this from within its own resources. When this is not possible, it often has already established links with other bodies that have the necessary complementary assets.

Capacity to respond

CSIRO's ability to develop research strategies and solutions that draw upon the full range of expertise found within the organisation is a particular advantage to Australia – and one that other research performing organisations cannot emulate in the same way. For this reason CSIRO is a central element in Australia's 'capacity to respond'. In effect, CSIRO delivers impact today but also preserves options for having future impact.[42]

Just as importantly, although less directly, CSIRO plays a pivotal role in the government's emergency response capability. While this is clearly the case with respect to a facility such as the Australian Animal Health Laboratory, it applies across the whole range of the organisation's capabilities, infrastructure and expertise. It is important to understand, however, that this is not about 'fire engines waiting for a fire'. The capacity to respond to an emergency is a by product (but a very important one) of having and using expertise and facilities for current purposes.

A country's science and technology capacity – people and intangible infrastructure as well as physical facilities – forms an important component of its broadly defined national security system. CSIRO's scale, diversity, linkages and status as a government research agency together make up a resource that can quickly develop and implement a response to a crisis requiring scientific research or a technical response. Examples of such emergencies might include a breach of quarantine, the appearance of a new disease, an influenza pandemic, a trade problem relating to chemical residues, a major pollution or land degradation event, or an issue relating to an international treaty that has the potential to directly affect Australia's trade, security or economic development.

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[42] For example, work in radioastronomy provided the basis for wireless LAN technologies that have wide commercial application.

Although a response to a crisis will be led by the responsible authority and often involve other research and science agencies, CSIRO provides one of the most important parts of this emergency response capability. One reason for this is that it provides the potential to assemble large, multi-skilled teams quickly, drawing on its in-house expertise and its linkages with other elements of Australia's science and research system. Another reason is that CSIRO forms a natural first point of contact when government needs urgent advice and action involving science, not least because CSIRO is able to draw on its extensive links with both the domestic and international science communities.

As discussed later, the planning processes used by CSIRO to allocate its resources take a forward looking approach and use an external scanning of the domestic and international environments that reflect this role. This is one reason why the government provides a (largely) one line appropriation to CSIRO. This buys capacity rather than projects from CSIRO – it is in effect an insurance policy, supporting a preparedness to deal with possibilities that flow from CSIRO's more directed activities that result from an expert analysis of Australia's needs and challenges conducted in the context of existing and emerging scientific opportunities.

Importance for risk management and risk sharing

From an innovation system perspective, a major benefit of the scale at which CSIRO operates and of the diversity of its research portfolio is that these allow it to manage risk. The ability of CSIRO to do this and to help its partners makes a significant positive impact on the effective operation of the innovation system.

As mentioned earlier, research is always uncertain and the more challenging the research the greater the risk of not achieving the desired outcome.[43] Moreover, only a small proportion of successful research produces significant returns. Having the size to manage a large and diverse portfolio of projects can help to manage this risk.

Because it receives appropriation funding, CSIRO is able to use co-investment approaches to share risk with firms that are themselves too small to maintain a portfolio of projects. In doing this, CSIRO's scale has allowed it to experiment with more flexible arrangements that help SMEs. Among other things, this involves using different fee arrangements. These include mechanisms (such as the use of royalty streams, revenue/profit sharing or success bonuses) that share the risk and rewards of the research. This can help compensate for the structure of Australian industry that tends to inhibit corporate research. Moreover, CSIRO's 'fast fail' approach to research management (discussed later) provides a more refined risk management strategy that both supplements and complements the scale advantage. In particular it can help limit the downside risks and prevent unnecessary investment in research that will not meet its agreed objectives.

[43] This does not necessarily mean that the research has failed. The knowledge that the desired outcome is not possible may itself represent a significant advance in understanding and open up other opportunities and new approaches.

Importance of scale to international reputation

CSIRO's scale, when combined with the excellence of its research and its status as a government statutory authority, makes it a significant player on the international scene. CSIRO's brand visibility plays an important role in creating awareness overseas of the excellence of Australian science, technology and technical infrastructure. Scientists overseas are aware of CSIRO as a world class institution and this flows through to the reputation of Australian science generally.

One of CSIRO's statutory responsibilities is 'to act as a means of liaison between Australia and other countries in matters connected with scientific research'. Having an international reputation is necessary to gain a seat and exert influence at international science and technology decision making bodies. The visibility and reputation of CSIRO serve to demonstrate that Australia does not freeload on world science but is contributing in a significant and respected way to the global generation of knowledge. Moreover, many international organisations still prefer to connect with government owned organisations in developing linkages and developing decision making procedures.

Having an international reputation for science excellence and for contributing to the international science effort, especially that addressing major global problems, can have immense and direct economic benefits. For example, because it participates in international science teams, CSIRO gains access to ocean data collected by other nations' satellite programs and their *in-situ* water measurements, such as the international "Argo" autonomous profiling float program. These data collection programs cost hundreds of millions of dollars per year and there is no way that Australia would be able to collect this data alone.

A reputation for world class science helps attract and retain the best researchers and gain the trust of overseas scientists. This can lead to the effective sharing of data, information and deeper forms of collaboration. The excellence and impact of CSIRO science provides membership of research networks that extend around the world. This allows Australia to draw on expertise (and gain access to intellectual property) that it does not otherwise have. Worldwide, in 2005 CSIRO was a participant in 962 international research activities involving leading scientific organisations and firms in the USA, Japan, Europe, and with developing countries, especially in Asia. In all, CSIRO has current collaborations with 75 separate countries.

Recognising the important role CSIRO plays in the international recognition of Australian science is not to argue that the science and research performed in other institutions is less than world class. In many cases it is clearly excellent. However, without the benefit of scale these institutions cannot have the visibility that an organisation the size of CSIRO can attain.

Importance of scale for planning

CSIRO occupies a unique position in the national innovation system through its ability to develop and mount large scale responses to major national challenges, especially those requiring a multidisciplinary response. In doing this CSIRO plays a role that goes beyond the boundaries of the organisation to bring together players from all parts of the national innovation system. In taking on this role CSIRO can have an impact that goes beyond the research community and that flows not just from the outcomes of the process, but directly from the process itself.

Combined with the continuity provided by appropriation funding, CSIRO's scale and breadth of expertise allow it to direct significant effort into identifying and analysing issues of national importance. In particular, the organisation can bring together multidisciplinary teams able to work over an extended period to identify creative ways in which to harness science and research to achieve national objectives and solve major problems. The development of CSIRO's National Research Flagships provides the clearest example of how this approach can work.

After evaluating the various options it identifies, CSIRO is able to plan a research strategy to address the problem in the most effective way. In doing this the organisation draws on its in-house expertise but also on other parts of the research and research user communities. In particular, CSIRO draws heavily on its linkages with research users (whether in different levels of government or the private sector) in developing and prioritising the various elements of the research strategy. This acknowledges that without the prior commitment of research users to implement the research results (which may involve a considerable financial investment on their part) the research will serve no immediate purpose.

Involving the research users at the early planning stage also recognises that the research solutions need to be those that the end users have the capability to exploit, not those that are the most elegant in scientific terms or that result in the greatest increase in scientific understanding. This does not mean performing less than excellent science. However, it can involve working to other than a purely scientific agenda. In working to achieve a defined outcome it is important to be pragmatic. The culture necessary to do this comes from the particular research domain in which CSIRO operates.

Significance of funding mechanisms

The commission's terms of reference require it to evaluate the decision making principles and program design elements that influence the operation of the innovation system and guide the allocation of funding. In considering this issue it is important to recognise the particular characteristics of different mechanisms of providing public support. It is also necessary to consider the interactions that can take place between public and private sector support and how these can affect the ability of an organisation such as CSIRO to meet its statutory responsibilities.

CSIRO receives funding through a variety of mechanisms: direct budget appropriation; grants and contracts from government; contract and fee for service work from the private sector; revenue from existing intellectual property; and revenue from management activities such as asset sales. While these are all important, it is the budget appropriation that defines CSIRO's role and allows it to make its most significant contributions to Australia's wellbeing. In particular, it is the appropriation funding, provided largely through a one line appropriation, which enables CSIRO to adopt a strategic, forward looking and holistic approach in developing its research portfolio.

Significance of appropriation funding

Without appropriation funding CSIRO would not be able to use its scale and breadth of expertise to address major national problems and to create or respond to large scale opportunities. It is not possible to initiate and pursue a ten or twenty year research program that brings together diverse players and organisations if you are operating with grants that guarantee funding for a very limited period and that have an uncertain chance of renewal, even if the program has achieved a significant output.

The budget appropriation, with its associated triennial funding agreements, provides for a degree of certainty and stability. This facilitates the strategic planning of research and investment in longer term, challenging projects, as well as the maintenance of capability. Appropriation funding supports basic infrastructure, including facilities, equipment and expertise. Just as importantly, it provides an essential base from which it becomes possible to invest resources into the development of long term research projects requiring the assembly of large teams of experts from several disciplines across different organisations. Grant schemes do not support such planning or cover the considerable overheads required to manage such projects. Neither do grant schemes provide the single point accountability within one organisation which is necessary for the effective management of this kind of large scale program.[44]

The government appropriation buys broadly defined outputs as well as the underpinning research capacity that allows CSIRO to use its own (competitive) resource allocation procedures to make its investment decisions. However, these procedures have to be in accordance with the organisation's strategic plan and the organisation has to respond to the national research priorities. CSIRO is also subject to detailed and specific outcome performance reporting requirements including those specified in its triennium funding agreement and required by its establishing legislation. CSIRO's appearances before senate estimates committees add a further layer of accountability and transparency.

One benefit for the government of buying broadly defined outputs and underpinning research capacity through the appropriation funding is that it provides CSIRO with a degree of independence. This is one reason the public has such a degree of trust in the organisation and why CSIRO is the organisation that many people prefer as a source of trustworthy scientific advice.

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[44] Single point accountability can involve the participation of external stakeholders – it need not be internal to the organisation.

If CSIRO makes comments about, for example, the safety of recycled water or the use of hormones in farm animals, the public treats the statement with confidence. This is because the organisation's funding does not depend on the advice that it provides. The community is likely to treat statements made on the basis of research funded by the private sector, or by a government agency with a particular policy agenda, with less confidence. A perceived conflict of interest can decrease trust as much as an actual conflict.

As well as allowing the use of sophisticated research planning techniques, the single point accountability of appropriation funding enables CSIRO to use world best practice research management. This provides a flexible approach to continuous research assessment and the redirection of resources to projects that will have the greatest impact. If accountability for project funding was spread between CSIRO and one or more funding agencies, this approach would not be possible.

A particular advantage of appropriation funding is that it facilitates sustained research into areas that the general community and business have not yet identified as important.[45] The competitive grants and contracts open to CSIRO usually focus on existing problems rather than on providing a means to develop technology to respond to issues not yet on their agenda.

The immediate customers for research may not recognise the wider implications of new scientific developments, or lack interest because of the time it will take to realise their potential. Scientific developments likely to have greatest impact on a sector can be outside its existing technology paradigm and the interests of its practitioners. However, if Australia does not follow up these opportunities, its industry or other Australian research users, may find their business disappears. Appropriation funding provides the means through which CSIRO can work on these issues and communicate their significance to its relevant stakeholders. Appropriation funding also ensures that CSIRO's work in these areas can take place at a scale that makes it globally relevant and so increase the probability that it will provide significant benefits for Australia.

Some characteristics of non-appropriation funding

Grants and contracts

Grants and contracts provide funds to selected areas and to specific projects, in accordance with the purpose (and criteria) of the funding scheme or individual contract. As such, they can provide a direct link between research users and research performers which can help in transferring the research outcomes to the customer. They have higher administrative overheads than appropriation funding, not least because of the competitive processes necessary to win them.

[45] The ARC supports basic research that advances understanding, but CSIRO cannot apply for ARC funding. As already discussed, grants are always subject to uncertainty and do not facilitate long term planning or a sustained effort, especially when it might take longer than three years to achieve significant results.

Reacting to opportunities for contract and grant work has benefits but too great a dependence on this kind of reactive external funding could create a research portfolio of many small, unrelated, short-term projects. The end result would be a fragmented, reactive research effort.[46] Moreover, a system that becomes too dependent on externally contestable funding can quickly lead to the loss of national capabilities, as demonstrated by New Zealand's experience in establishing its Crown Research Institutes.[47]

Fortunately, a purely reactive approach to external funding opportunities is not always necessary. For example, the strategic development of major research activities carried out in partnership with relevant stakeholders can help create opportunities for contract and grant funding. In other words, a significant research planning effort can identify opportunities that other stakeholders participating in the planning process value and may chose to support. As already mentioned, however, this collaborative development of a national research response to a national challenge is itself expensive and requires funding.

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[46]It is also worth noting that the transaction costs associated with applying for a grant can be considerable, not least because for many grant schemes only a relatively small proportion of applications receive funding. There are considerable opportunity costs involved in preparing a high quality grant application because this will occupy the most senior scientists – and this ignores the administrative and other costs of the funding body – which often include the time taken by very senior and experienced scientists conducting peer review of applications unlikely to receive funding.

[47] The report *An Appraisal of Crown Research Institutes 1992-2002* prepared by the New Zealand Ministry of Research, Science and Technology with assistance from the Crown Company Monitoring Advisory Unit concluded that he strongly competitive funding system for CRIs was:

- Affecting the ability of CRIs to maintain core competencies in key but unfashionable areas of research eg taxonomy, plant physiology;
- Leading to instability of employment, with redundancies lowering a CRI's ability to compete for future funding in specific areas;
- Reducing employment security, making recruitment and succession planning difficult;
- Encouraging CRIs to take decisions that are to their own benefit but not in the national interest (eg disposing of certain capabilities that may be redundant to their current business);
- Allowing research purchasers to take decisions that might compromise long term national interest;
- Limiting the ability of CRIs to manage research because most contracts are for three years but research may require 8-10 years to produce an outcome;
- Cutting promising research programs short as priorities change;
- Creating an unnecessary administrative burden;
- Leading to gamesmanship to secure funding, even at the expense of other CRIs;
- Resulting in funding decisions that do not recognise or take into account impacts on the CRI – eg destabilisation and demoralisation of CRI staff;
- Leaving important responsibilities unfunded – eg consulting with Maori and government departments; graduate training work and experience; collaboration with universities;
- Diminishing public trust in CRIs because of their increasing commercialisation and lack of neutral experts;
- Making some collaboration between CRIs and universities more difficult;
- Hindering the ability to share risk with industry and leading to a breakdown of trust;
- Creating significant tensions between public good role and commercialisation responsibilities;
- Putting too great an emphasis on financial performance – which can hinder negotiations with potential partners, including industry.

Most granting schemes support projects that are small compared to the size and timescale of programs that appropriation funding can support. Moreover, research funded through grants and contracts depends on the infrastructure provided through appropriation funding. This is important because to the extent that grants do not cover the full cost of the research they purchase, the acceptance of a grant can reduce the level of appropriation funding available for other purposes. In effect, a grant is one means through which external public bodies can draw on CSIRO's appropriation funding and affect its overall research strategy. Because grants originate from public sector organisations, involve public funding and generally aim to produce public good outcomes in the public interest, the necessary subsidy of grant-supported work from appropriation funding does not result in any conflict with CSIRO's roles and objectives. However, grants do reduce some of the flexibility that CSIRO has to allocate its appropriation funding purely according to its internal assessments.

Contracts for research or the provision of scientific and technical services differ from grants in that they usually fund the full costs of the work they are purchasing, including the cost of using the infrastructure and other overheads. The organisation seeking such work can generally capture all its benefits and in these circumstances there is no need or reason for the government to subsidise the work.

Because contracts cover full costs, performing contract research or providing scientific services to industry on a full fee basis does not reduce the work carried out using appropriation funding, but adds to it. By increasing the use of infrastructure provided by appropriation funding, contract research for Australian industry increases the return on national investment in science and technology infrastructure.

Co-investment

In some cases CSIRO may negotiate partnerships with industry to share the costs, risks and benefits of the research. This can provide an opportunity for CSIRO to capture directly some of the financial benefits that arise from the application of its science, while making it easier for a firm (especially an SME) to accept the risks of the research failing, or of it not having its projected commercial impact. This co-investment role can be important in responding to the market failures that result from the size structure of Australian firms, as previously discussed.

In performing work directly for industry, CSIRO is bound by competitive neutrality principles and the 'yellow pages test'. It is not the role of CSIRO to crowd out business, just as it is not CSIRO's role to provide subsidies to business.[48]

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[48] However, there is one set of circumstances in which CSIRO might provide services at less than full cost. This is where the size of the Australian market for such services is too small for the establishment of a fully commercial operation but the service is necessary for the effective operation of the industry. If CSIRO is able to provide the service, but at a level of precision or sophistication beyond that required by the customer, it might be appropriate to charge at a level commensurate with what the customer needs rather than what CSIRO can provide. An example might be where CSIRO has the capacity to provide analytical services using facilities more expensive and sophisticated than those required to provide the level of sensitivity and precision an industry needs. Especially where the facility is not in full use and practice is necessary to maintain capability, both parties can benefit.

Revenue from IP

CSIRO receives revenue that represents a return on initiatives the organisation has taken in the past. Licence fees for the use of intellectual property developed from budget-funded research are obvious examples, as are income streams from spin-off companies. These depend not just on CSIRO's research skills and research excellence but also on its ability to recognise commercial potential and to market the technology it has developed in the most appropriate way. These earnings are an obvious and direct return on the government investment in research and development and provide a partial indicator of one impact. Charging for the exclusive use of IP developed by CSIRO not only makes sense from CSIRO's own perspective, it also provides a means of ensuring that private firms do not gain an advantage against their domestic competitors at the expense of taxpayers.

Because revenue generated from IP is a benefit of work already completed, it is available to reinvest in emerging research opportunities chosen by CSIRO – unlike income for contract research, which the organisation has to spend on the work necessary to complete the contract. Revenue from existing intellectual property can provide an income stream rather than a one-off payment, presenting a wider range of choices than the other external revenue sources.

'Additionality'

Public funding for science and innovation is not meant to be a substitute for private sector funding but should support activity additional to that the private sector would support. When the government is the primary user of the research it funds, this does not become an issue. Work falling into this category includes that in the 'role house' categories of developing science-based solutions for the community; and solving major national challenges aimed at improving the quality of life of all Australians and reducing national costs. However, when the research has the potential to assist industry directly, the question will always arise as to whether the private sector would have funded the research in the absence of government funding.

When CSIRO is performing fully funded contract research or providing scientific services for a fee that covers the full costs of providing the service, the issue of substituting for private sector funding does not arise. Similarly, in conducting research to advance the frontiers of science, CSIRO is unlikely to be operating in an area that Australian business would support by itself.

The question of whether CSIRO is supporting work that the private sector should fund becomes most acute when CSIRO delivers incremental innovation for existing industries.

Given the arguments presented previously about the size, structure and capabilities of Australian business preventing the private sector from occupying certain niches in our national innovation system, the possibility that CSIRO research might substitute for business funded research is much less of an issue with respect to CSIRO's core role of creating new or significantly transforming existing industries. Most Australian firms are not sufficiently large to mount major research efforts aimed at developing breakthrough technologies.

Important though it is, the issue of 'additionality' is not clear cut. Even if the private sector would have performed certain research in the absence of public support, it might have done so in a different way. For example, in deploying a lower level of resources, or the same resources over a longer time period, it may have taken longer to achieve the necessary outputs – and in a highly competitive environment, speed is of the essence. A lack of public support might have produced a lower quality output – perhaps because the technical resources available to the private sector, or the breadth of expertise available internally to single firms, might have set limits on the means used to tackle the problem. Moreover, while the private sector might be capable of funding research that it needs to maintain its operations, it might have other options available that could disadvantage Australia. For example, major resource companies that operate globally might decide to use easier minerals deposits overseas than to continue to work with their more problematic Australian resources. Publicly supported research might help retain operations in Australia.

There are other issues to consider. For example, performance of the research by an organisation such as CSIRO can develops linkages that can have much broader benefits than finding a solution to an immediate problem; and when CSIRO uses its own funds for research it can make its findings available to every Australian business, community group or other organisation able to use them – whereas, if a firm funds the same research it will appropriate to itself the findings to gain an advantage over its competitors. The overall benefit to Australia might well be greater in the former case. More generally, when the private sector manages research it does so to maximise its financial return. When CSIRO manages research it has an interest in all the impacts that the research might have, including the non-financial impacts – the spillovers and second order effects that might have wider benefits.

As a further example of the complexities that exist, it is worth considering the public's confidence in CSIRO. If CSIRO were to perform research that allowed it to reassure the Australian community, for example about the safety of a genetically engineered plant or of novel energy technologies, the impact of the reassurance might depend on whether industry had funded the research or CSIRO had funded the work as a matter of public interest from its appropriation funding. The issue is not that the research or its results would have been different; however, the perception of the public about the independence of the research might well be different.

This being said, CSIRO's position is that it does not fund research that the private sector is likely to support itself. A decreasing proportion of CSIRO's appropriation resources goes into the incremental innovation roles; and an underlying principle of CSIRO's business models is that CSIRO will not subsidise activity that business should pay for itself.

Given the risk averse nature of much of Australia business, and the significance of SMEs in our economy, it is not always easy to make a decision on whether CSIRO's support will substitute for work that the private sector would otherwise fully fund. This provides an additional reason for adopting a co-investment approach which provides CSIRO with an ongoing share of the benefits that arise from the application of its research by its co-investors.

If the private sector view is that the research has a high level of certainty and will produce significant benefits, it is less likely to agree to co-investment proposals, preferring to pay the full costs of the research upfront and retain for itself all the expected returns. The greater the level of uncertainty and risk, the more likely firms will be to agree to share the costs, risks and benefits.

Discussion

The table below presents data on the source of CSIRO's research and services (R&S) revenue. It demonstrates the way in which non-appropriation funding has been increasing and in particular the significant increases that have been taking place in IP revenue. While total revenue has been growing, that from 'services and consulting' has been decreasing. The main reason for this is that in 2002-03 CSIRO realised that it was using appropriation funding to subsidise these activities, the benefits of which were flowing entirely to the recipients of the service. The organisation therefore decided to stop this subsidy. The 2002-03 appropriation subsidy was estimated at $24.5m (29% of total service and consulting expenditure) and by 2004-05 it had been eliminated. While this led to a reduction in revenues for these services as demand decreased, this has not affected the total level of research and services revenue. It has also meant that the organisation has had higher levels of appropriation funding to allocate to research addressing major challenges and that clearly fall into the category of requiring support from public funding.

Investment Domain ($ m)	2002-03	2003-04	2004-05	2005-06
Coinvestment	179.8	194.0	209.4	218.1
Services & Consulting	83.7	78.7	60.9	61.9
IP Revenue	13.8	22.0	20.4	37.1
Total R&S Revenue *	275.4	296.2	280.9	309.1

* Total R&S Revenue includes work-in-progress and deferred revenue adjustments, individual elements do not.

As this example illustrates, the challenge for CSIRO is to balance funds coming in through different mechanisms, given the agency's roles, responsibilities, mandate and capacity.[49]

The challenge for government is to retain the range of mechanisms it has available and to use them to maintain an effective innovation system, the differentiated components of which interact to optimise the return on the nation's investment in research without compromising other desired government outcomes, such as policy advice, a broadly educated workforce and facilitating the development of new and emerging industries.

[49] For example, it is easier to attract external funding for incremental improvement work than for research aimed at major transformations of industry, which is much riskier and longer term. Yet CSIRO's major responsibilities fall into the major transformation area.

On CSIRO's part it is possible that the desire for extra funding could create a perceived tension between its agreed research strategy and the chance to respond to opportunities for contract research or grant funding. There will always be some opportunistic searching for external funding. This is the case especially when additional funding is necessary to maintain staff levels or to ensure the effective use of a facility that might be important strategically but happens to have spare capacity at a particular time. Expertise is easy to lose but can be difficult to develop quickly.

The mix of funding might also raise issues when considering how best to ensure that a particular research output has maximum impact. This can occur if making the technology generally and freely available would maximise its economic and other impacts but tightly controlling IP rights and entering into exclusive licence arrangements might increase the return to CSIRO itself.

CSIRO's role is to promote the Australian interest and to maximise the return to Australia. In the case of public good research there is generally no conflict. In the case of research having the potential to benefit industry, the issue is seldom pronounced because in many cases the conversion of CSIRO science to a genuine innovation will require substantial investments by partner organisations. These investments may not take place unless the partner organisations are able to reduce their risks by knowing that none of their competitors will have access to the same technology. In these circumstances, the national interest and CSIRO's interests are in close alignment. Even in this situation, however, it is important to recognise that for various reasons the IP might best be held as a trade secret and that undue reliance on patenting as proxy measure for impact can have the perverse effect of decreasing the probability that the technology will have direct impact. Nevertheless, there is no reason why individual firms should benefit from taxpayer funded research unless they pay a full commercial rate.

The underlying point is that research will not have any impact unless someone makes the investments necessary to apply it. It is a measure of CSIRO's increased focus on impact that the funds flowing to the organisation from the exploitation of its IP have increased significantly over recent years and in 2005-06 is around $37 million.

Importance of collaboration

While CSIRO plays a unique and necessary role in the national innovation system, it does not stand alone. One of the important characteristics of CSIRO is the way that it has integrated its operations with those of other parts of the system. In doing this the organisation has worked to develop and create national advantage from the synergies that come from combining different roles, functions, specialisations and approaches to achieve a common end.

CSIRO is large but has a permeable boundary, with a wide range of formal and informal relationships in place with other parts of the research, science and innovation systems.[50] All parts of the organisation have collaborations and partnerships of various kinds. Some relate to the performance of research and CSIRO, for example, participates in more Cooperative Research Centres than does any other organisation. Other collaborations relate to the application of research results, the sharing of facilities, training or joint appointments. All depend on bringing together complementary skills, facilities and approaches to achieve an outcome that the individual partners could achieve by themselves.

CSIRO's strategy in developing collaborations is to capitalise on the differences that exist; to concentrate its own efforts on those activities that no other organisation can do better; and to operate in a way that strengthens the whole innovation system to achieve best national benefit outcomes. Collaboration is not an end in itself but flows from an identifiable business need in which the benefits of collaboration will exceed its transactional and other costs.

Collaborating partners include organisations operating in the higher education, government and business sectors. Moreover, as a statutory authority CSIRO plays a direct role in supporting government. This requires the organisation to anticipate the need for, and to provide technical advice on, policy issues; and to respond to government needs for research. As discussed elsewhere in this submission, it is also important to recognise that CSIRO's partners may be overseas as well as in Australia. International collaboration can have very significant benefits, not just for CSIRO but for Australia.

A significant proportion of CSIRO's partnership activity aims to transfer research results to those able to use them. CSIRO uses a wide variety of transfer mechanisms ranging from publication and seminars to secondments, training courses, the provision of technical and consultancy services, advising government, providing post-doctoral experience, the licensing of intellectual property and the establishment of spin-off companies.

CSIRO also supports the education of scientists, from school to post-doctoral level, especially through providing resources and access to facilities and expertise that the universities do not have themselves.

The active and direct linkages and partnerships that CSIRO cultivates are the visible side of a substantial network of less tangible and indirect interconnections. While these are difficult to measure, they are of considerable significance. Researchers from other organisations, and research users from all sectors of society, draw upon and develop the intellectual products coming from CSIRO, often with no direct contact with the individual researchers or the organisation itself. (Just as CSIRO scientists use the scientific literature and draw upon the work of other scientists from around the world.)

[50] The $97 million Flagship Collaboration Fund provides one example of formal arrangements that exist. By offering opportunities for universities, research agencies, individual researchers, graduates and post-graduates to engage in groundbreaking scientific research, the Fund creates long term collaborative partnerships.

Industry researchers benefit from CSIRO research without any need for tangible partnership arrangements. While this does not produce a direct return to the organisation, it adds to national welfare directly and indirectly – not least in promoting Australia's reputation as a scientifically advanced nation contributing its share to world knowledge.

Importance of external advice

CSIRO has an enterprise-wide approach to developing its research strategies. The research portfolio of the organisation is not just an amalgamation of the decisions made by individual scientists and divisions. Rather, it is the outcome of explicit planning, decision-making and funding allocation processes that operate from within an organisation-wide strategy.

Equally important is that this development of research strategies involves interactions and consultations with research user groups, as well as with government. CSIRO has in place formal advisory arrangements (the Sector Advisory Councils, Flagship Advisory Committees, etc) so that external stakeholders can provide direct advice and comment on the organisation's overall research strategy. This means that as well as having direct influence at the project level (through customer/supplier relationships), stakeholders are also able to help shape the allocation of appropriation funding.

This external influence, operating through formal and informal dialogue, serves to ensure that CSIRO's strategies respond to stakeholder needs and capacities. Moreover, the interactions that take place operate in two directions. As well as feeding information into CSIRO, they also help keep industry, government and other stakeholders informed about emerging opportunities and possibilities. This serves to complement CSIRO's other awareness activities and helps feed broad technological intelligence to those who need it for their own planning and strategic development. In doing this, these processes also play a role in improving the absorptive capacity of the innovation system.

CSIRO – innovating to increase impact

There is no doubt that CSIRO has had and will continue to have a major impact across all areas of Australian life or that Australia would be a very different place were it not for the contributions that CSIRO has made over the last 80 years. Nevertheless, the environment within which CSIRO operates is changing and CSIRO has had to respond to these changes by clarifying its roles and refining the ways in which it operates. In practice this has meant CSIRO has had to innovate, introducing changes in its planning, management and evaluation techniques to improve its performance and ensure that it remains one of the world's leading research organisations. The challenge for large organisations such as CSIRO is to foster creativity while providing the transparency and accountability that are necessary to increase focus on practical outcomes.

A particular focus of this internal innovation has been to make CSIRO's research and other activities more effective – to ensure that the government and Australian taxpayers receive the maximum return possible on the investment that they make in CSIRO.

In making these changes CSIRO has recognised that the impacts the government is seeking often go beyond simple economic outcomes; and that as a commonwealth statutory body, it is not CSIRO's responsibility to do work that the private sector should be doing for itself. As a result, the organisation's strategic plan and the changes introduced to ensure its effective implementation flow from the arguments for government funding of science. The central theme is that of looking outwards from the organisation to produce a better outcome for Australia. This means that the approaches CSIRO uses have some differences from those that the private sector might employ, because these concentrate on what is best for the firm.

If it is to serve Australia effectively, CSIRO has to strive for excellence in all that it does but in particular it has to produce excellent science. However, increasingly superimposed on this foundation of excellence in research are the concepts of relevance and impact.

The areas of science in which CSIRO invests the resources it has available are those which are important to Australia. The problems that CSIRO addresses are not necessarily those that offer the greatest scientific challenges – they are those that present pressing issues for Australia. More than this, the ways in which the organisation addresses these problems are those that CSIRO believes are most likely to develop practical solutions and create the opportunities that have the potential to improve the well being of all Australians.

CSIRO uses a variety of methods to promote scientific excellence, ensure relevance and increase the certainty of the impact of its activities. These operate at the level of the individual scientist (for example through the use of annual performance agreements and reward structures) to the top level management processes of the organisation. The same processes help ensure the excellence of the support – both physical and intangible – that they scientists receive.

Of particular significance are the organisation's Science Investment Process (SIP), Performance Management Framework and Science Assessment Process. Associated with these is a variety of stakeholder engagement processes that allow representatives of other parts of the innovation system to participate in the development of CSIRO's overall strategic direction. Also important is the emphasis that CSIRO gives to effective project management throughout the range of its activities and the operational processes it has introduced to facilitate and encourage technology transfer. All of these processes flow from and contribute to a commitment to ensure the quality of the organisation's underlying capabilities. They reflect a commitment to active management at the enterprise level and go beyond the use of diagnostics to generate genuine and transparent change.

In addition to the planning, management and evaluation process that operate on a continuing basis, there are other less regular or *ad hoc* activities that help identify the impact that CSIRO is having and can produce ideas on how to increase these impacts. These can include formal cost benefit or cost effectiveness studies carried out by divisions, customer surveys of various kinds, and *ad hoc* reviews. CSIRO has provided the Commission with copies of previous benefit cost studies conducted on CSIRO projects and Attachment 4 provides a summary of the outcomes of some previous studies.

Recently the organisation has conducted a major exercise assessing the potential and directions of Australia's manufacturing industry sectors to benefit from research, the findings of which will feed directly into the planning and funding allocation processes. Other relevant activities are a mid-term review of the Flagship programs and an extensive exercise to increase the efficiency of our research support services so that a greater proportion of CSIRO funding can go directly to research. As mentioned later, CSIRO has also started work on a major review of its impact using a real options framework. This will provide direct and rigorous analysis of the impact of selected CSIRO programs but will also provide information on how to improve CSIRO research planning and management processes.

Scientific excellence

In working to maximise its effectiveness, CSIRO has reaffirmed that its primary responsibility is to produce excellent science and that this commitment to excellence provides a necessary foundation for everything else that it does. Excellent science produces excellent outcomes.

Scientific excellence requires creativity, probity, independence and integrity. Excellent science is rigorous, objective, capable of being repeated, and discriminates between alternative hypotheses. However, as discussed in Attachment 5, quality by itself is not a sufficient measure of scientific excellence, except when one is dealing with basic, investigator led research. When research has an intended outcome, the extent to which the research achieves that outcome is an essential component of the excellence of the work. Among other things this has to encompass fitness for purpose of the research outcome – the research output has to be usable by the research customer.

There are two main tools for assessing the quality of science as science. These are peer review processes and the measurement of citations – the number of times other scientists cite in their own work the work of a particular scientist. While there are problems with both these methods, they do provide important indicators of scientific quality. Moreover, citations provide a fairly direct measure of scientific impact, as the number of citations is a direct measure of the extent to which other scientists are drawing upon the work of the cited scientist in their own work.[51]

Peer review plays an important role in the science assessment process discussed below, where it covers both the quality of the science and the importance of the science to users. Science citation analysis is also an important tool with CSIRO now conducting a citation analysis of publications having CSIRO authors every three years (the most recent being in 2002 and 2005).

Based on the Institute for Scientific Information's (ISI) Essential Science Indicators for 2004–05, (monitored across 3 400 institutions), CSIRO ranks in the top one per cent of institutions worldwide in 13 of the 22 research fields used to classify research publications. The 13 fields are:

- Plant and Animal Science
- Environment / Ecology
- Geosciences
- Agricultural Science
- Chemistry
- Space Science
- Biology and Biochemistry
- Microbiology
- Clinical Medicine
- Engineering
- Physics
- Materials Science
- Computer Science

The average citation rate for all CSIRO publications included in the ISI database increased to 10.46 for 2005-06 from 9.87 for 2004-05 and 9.18 for 2003-04. This is above the ISI average of 8.62 and the Australian average of 9.08.

Technology is often much more local in its application than is science. This can mean that, other things being equal, it would not be surprising if excellent technological research receives a much lower rate of citation than scientific research. Nevertheless, despite the role that CSIRO plays within Australia's research system, CSIRO's citation rates are higher than those of any other Australian organisation apart from the Australian National University.

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[51] That high citations can result from other scientists criticising a paper does not lessen the impact the paper is having, although it may say something about the quality of the science. In considering the advancement of knowledge it is important to appreciate that negative results and research that closes of options is not necessarily unsuccessful – it advances knowledge, even when the results obtained were no those expected or hoped for.

Measuring fitness for purpose is more difficult than measuring science quality. The best way to seek information in this area is to seek direct feedback from customers – and to monitor repeat business, when this is relevant. CSIRO does conduct regular customer value surveys and the submission notes the results of these surveys in a later section.

Science investment process (SIP)

In responding to the changing environment within which it operates, CSIRO has recently introduced a formal, transparent, science investment process (SIP) that operates at the enterprise level.

This science investment process works to ensure relevance. At the same time, it assesses the potential for research in different areas to have a serious impact within Australia. While the process is under continual development and is constantly refined, its purpose is to provide a systematic and deliberate approach to managing the organisation's research investment portfolio. The process combines analytical and strategic processes that build on explicit criteria and use data from external sources. This has the intent of allowing business, government and other stakeholders to inform and influence CSIRO's overall research strategy by providing information, analysis and comment.

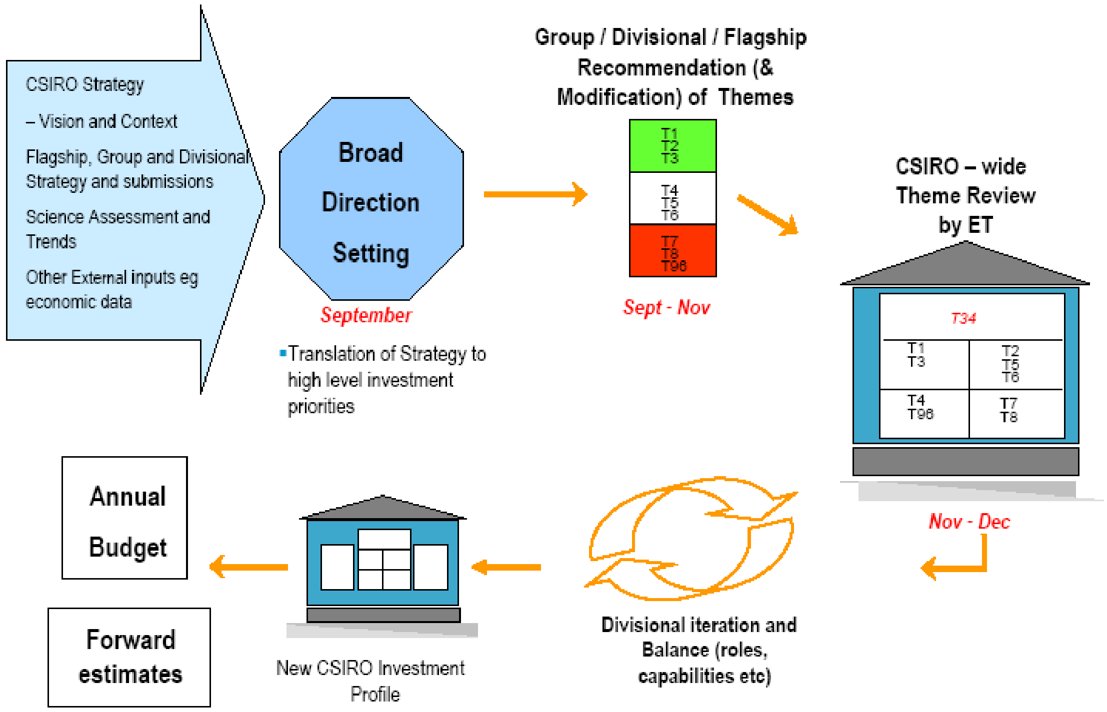
In conducting SIP as a high level process, CSIRO's executive team do not evaluate research opportunities in isolation. They also take into account the need to maintain an appropriate balance between all CSIRO's roles and responsibilities. This includes the overriding need to maintain the capabilities necessary to preserve as many as possible future options for research and impact.

The principal goals for SIP are to:

- increase the transparency and rigour of decision making right through the organisation;
- encourage longer-term perspectives in science planning;
- tap into CSIRO's distinctive strengths in cross-disciplinary initiatives;
- increase linkages across the organisation;
- promote a trust-based approach through which the correct people are making the appropriate decisions; and
- make evolutionary rather than revolutionary changes to CSIRO's portfolio.

The diagram below summarises the science investment process. Attachment 6 summarises the kind of data that feeds into the SIP process and helps inform CSIRO's assessment of the relevance of possible research to Australia and its potential impact.

Science Investment Process Overview



The key steps in SIP are: broad direction setting; a theme-based review; and an iterative cycle to smooth out the impact of any unintended consequences of the review. A primary focus of the process is to increase the relevance and impact of CSIRO science. As such it is one of the tools that CSIRO uses to maximise the return the government receives from its appropriation investment.

By working to focus CSIRO skills and energies on the most important issues for Australia that are susceptible to these skills, the science investment process provides a formal *ex ante* evaluation of research opportunities that feeds directly into the funding allocation process.

Broad direction setting (BDS)

In the BDS process the senior executives of the organisation set broad directions for research investments in the following year and beyond, translating CSIRO's strategy into medium term investment priorities. In doing this they take into consideration a large array of internal and external factors such as global science trends, advice from industry, government research priorities, economic data and assessments of comparative research strengths. (See table below) Consultation with both government and private sector stakeholders is critical in preparing the background material that forms the basis for SIP. This analysis takes place around the 'industry community areas' listed in attachment 7.

The BDS criteria (see table below) provide a guide through issues associated with relevance and impact. They provide a basis for asking critical questions about CSIRO's remit, roles and future direction. They address, for example: whether CSIRO should be engaged in the area of research (relevance), the likelihood of adoption (impact), and the competitiveness of CSIRO's research (impact).

Relevance	Value from R&D Size of Area (industry / market size, growth rate, employment, export etc) Addressable benefit to Australia (social, economic, environmental) CSIRO should be engaged Fit with CSIRO role vs other members of NIS Responsive to National Research Priorities Relevance of R&D (Science and Technology is a key component)
Impact	Likelihood of adoption State of "receptor" system Willingness of partners / receivers of technology R&D productivity / potential CSIRO research competitiveness (now and future networks)

The output of this broad direction setting phase is the BDS document which outlines the investment priorities agreed by the executive

The Theme Review Phase

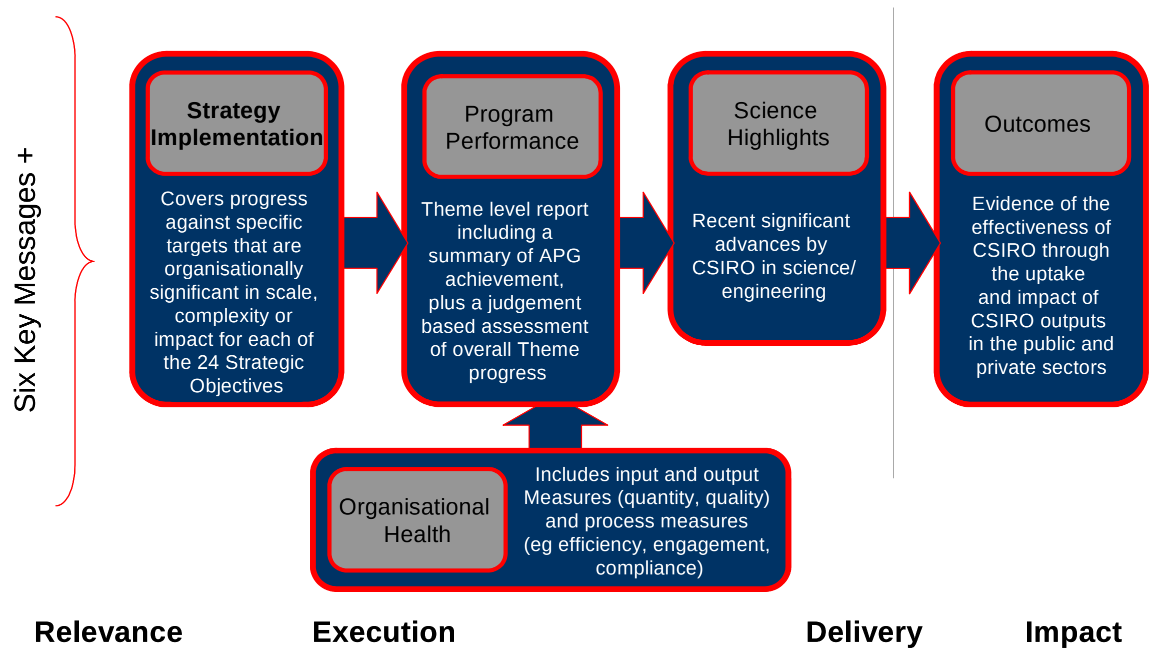
Following release of the BDS document, Divisions, Groups and Flagships examine how they can give effect to required directional shifts over appropriate timeframes. Senior scientists and research leaders across the organisation evaluate their activities against the theme review criteria (see the table below), paying particular attention to relevance and impact issues. The Executive Team (ET) then reviews the recommended research themes to identify cross organisational synergies and agree on investment levels. The output from the theme review is a series of short Division and Flagship specific documents that provide feedback on the senior executive's investment decisions. Divisions and Flagships use these documents to develop detailed budgets in line with the usual budget process (led by Corporate Finance).

As shown in the table below, the assessments of relevance and impact at this stage take place through the 'two lenses' of 'proritisation' and of 'judgement/balance', with the former of these having a more strongly objective basis than the second.

	Prioritisation	Judgment / Balance
Relevance	▪ Significant potential capturable benefit for Australia (Industry/ Community) ▪ Aligned with NRP or stated Government/industry priority area ▪ Delivery of Science and Technology is key to outcome	▪ Builds important capability in CSIRO with broad applicability (including Intellectual Asset / IP) ▪ Results in valuable additional benefits (eg.reputational enhancement, Australian global positioning) ▪ Top leadership commitment ▪ Aligned with CSIRO strategy (CSIRO role in NIS)
Impact	▪ Distinctive (and differentiated) science (Science Quality) ▪ Theme (researcher's) track record of delivery (last 5 years including delivery of scientific outcomes) ▪ Clear community / industry delivery pathway (including IP / Knowledge diffusion pathway)	▪ Science "hotspot" ▪ Appropriate leadership capacity ▪ (Divisional performance and competencies) ▪ Staff "achievability" (Recruitment / refocussing) ▪ Appropriate investment level ▪ Level of technical uncertainty ▪ Level of other risks – Political, Legal, Cultural, reputation

Performance Management Framework

Every four months CSIRO prepares an *Organisational Performance Report* for its Executive Team and Board. This report, with a focus on delivery and execution, assesses five broad elements of performance: strategy implementation, program performance, science highlights, outcomes and organisational health. (See figure below for a summary.) The performance management framework underpins accountability, both within CSIRO and between CSIRO and its various stakeholders, including the government, parliament and general community.



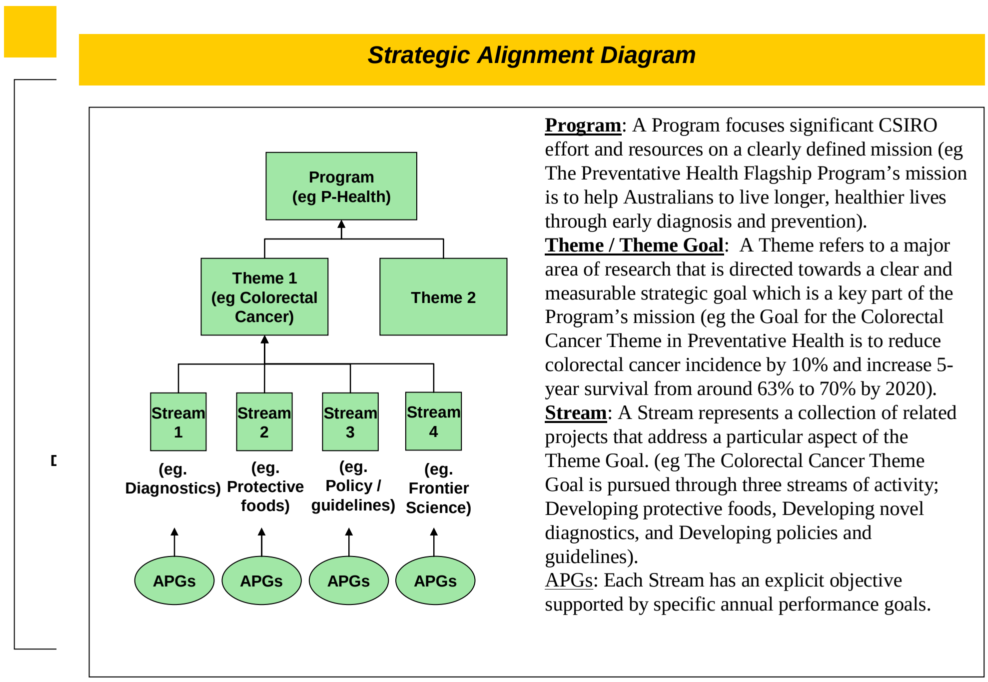
CSIRO has provided its most recent organisational performance report to the commission. The report makes it clear just how much CSIRO management emphasise the need to maximise the return on the government's investment in CSIRO; it also demonstrates the sophistication of the processes and the level of monitoring that CSIRO uses to do this.

While all parts of the performance management framework are important, the program performance component is especially relevant for the commission's study, as are the science highlights and the outcomes components. The next section provides a brief description of the program performance framework, while the 'impact' section of this submission deals with science highlights and outcomes.

Program performance framework

The program performance framework provides an effective means of managing research to achieve impact. It has the further advantages of improving communication about research projects within CSIRO and of simplifying communication with external stakeholders. This is because the framework has introduced a single and simple terminology for describing and organising research activities.

The diagram below illustrates in general terms CSIRO's research program structure which underpins the program performance framework.



Each research program consists of a number of themes. Themes are about outcomes – a defined value proposition having identifiable economic, social or environmental impacts. External stakeholders, often through CSIRO's sector advisory councils, play an important role in validating themes and their relevance to Australia. All themes consist of a number of streams, which themselves encompass projects.

Because themes focus on external impact, this framework helps prioritise decisions about resource allocations. Just as importantly, the processes involved in managing themes and streams has made very explicit the importance of engagement with public and private sector stakeholders in order to ensure maximum research impact and effective delivery.

The program framework is built around outcomes. In other words, the management processes centre around the achievement of impact through the adoption and use of the scientific outputs, not on the production of outputs themselves.

Every theme has a goal, which has to be an outcome. Each stream has an objective – which can be an output or an outcome. Each of the stream objectives has at least two annual performance goals.[52] These have to be an outcome, an output, a major decision or the commencement or completion of a major activity. The annual performance goals describe the progress necessary in the year ahead to be on track in achieving the stream objective. A key to the process is that it places as much emphasis on engagement with stakeholders as it does on science – path to market issues are critical from the planning stage, to the extent that early proposals can have annual performance goals for engagement but not science.

One consequence of adopting this framework has been that decisions might be made to stop work, not because it lacks scientific quality or promise, but because for reasons that may be outside the control of the scientists concerned, it has become apparent that the intended outcome is not achievable. This might be a result of competing technologies developed elsewhere, a lack of interest, commitment or capability among the possible research users, or for some other reason. Conversely, a decision might be made to accelerate a project because changes in the external environment increase its urgency.

This ability to monitor and take decisions about research in the context of both science and engagement with a view to outcomes, can facilitate the rapid reallocation of resources to more promising projects. For this reason some authorities refer to this approach as 'fast failure' but this can be misleading. A decision to reallocate resources does not necessarily imply the research has failed; it might simply be that the non-research capability necessary to convert an invention to an innovation is not available in Australia.

Science assessment process

SIP and the performance management framework are *ex ante* processes. They place CSIRO's funding where it will have the greatest impact and monitor the decisions that have been made to ensure that they are effective.

The science assessment process is an *ex post* process that evaluates the work conducted within and by divisions. The process comes from the requirement in CSIRO's current triennium funding agreement that the organisation undertake a continuing process for the assessment of its research performance. This assessment has to ensure CSIRO's research is demonstrably of a high quality, as measured against the world's best research. The assessment has also to consider whether the

[52] One of these will relate to the science, the other to engagement with delivery partners.

research is appropriate to the government's objectives in funding CSIRO. As already made clear, this requires excellence not just in science but also in its application. CSIRO's science assessment process has a close alignment with the broader and evolving Research Quality Framework and has the support of the government.

The science assessment process started with a review of the Division of Entomology in February 2005 and by the end of June 2007 will have covered all of CSIRO's divisions.

The science assessment process uses external, expert committees of three to five members, predominantly from overseas, to review each CSIRO division in turn. At least one of the external members is from an end-user rather than a research organisation. In addition to these external members, the Executive Director Science Planning, or his nominee, is a member of the committee.

The terms of reference for the committee relate to the:

- quality of the division's scientific capabilities and science outputs
    - distinctiveness and relative standing with respect to leading international groups
- relevance of these capabilities to the division's themes and to achieving the proposed outcomes
    - whether the theme outcomes are feasible given the science base
- development of researchers and capabilities
    - divisional emerging science plan
    - involvement in the supervision of postgraduate students and postdoctoral researchers
- impact of internal project management/selection processes on maintaining quality and relevance in the scientific outputs of the division

Following their consideration by the CSIRO Board, the assessment reports, along with any proposals for follow-up action prepared in response to the assessments, go to the *Committee to oversee the publicly funded research agencies' performance assessment process*, chaired by Australia's Chief Scientist. This committee reports to CSIRO's portfolio minister. CSIRO's annual reports contain summary results of the review and details of the follow-up actions taken in response to them.

The first two years of the science assessment cycle have confirmed the appropriate match of CSIRO's research capabilities, as a mission-driven organisation, against the two dimensional criteria of research community impact and industry/community impact.

The reviews also continue to re-affirm the high calibre of CSIRO's science; the clear impact of CSIRO's science at the regional, national and international level; impressive linkages and delivery with relevant industry groups; a high degree of enthusiasm by staff at all levels; that emerging science directions are appropriate; and that world class status is within the reach of additional research groups in CSIRO through enhanced focus, mergers and the targeted recruitment for senior scientists.

Project management

Top level processes for planning, management and evaluation are critical to the success of any organisation but their effectiveness will depend to a large degree on the competencies of the people working in the organisation and the tools they use to perform their work. The basic unit of work within CSIRO is the project and effective project management has benefits that spread across the whole organisation. For this reason CSIRO has put significant effort into building the project management skills of its staff and into providing them with the tools necessary to support these skills and to provide the information they need to exercise them effectively. Tracking of the organisation's project management index shows steady improvement in the overall quality of project management in CSIRO across the last three years.

Technology transfer operations

CSIRO carries out research in the public good and to serve the national interest. However, it is very aware that the most tangible benefits to Australia do not arise from its performance of research but from the use and application of its research outputs. Indeed, CSIRO has the statutory functions to 'encourage or facilitate the application or utilisation' of its own research or research performed by others (see Attachment 1).

For this reason CSIRO strives to achieve impact not just through its planning and management processes but through its day to day operations. Accordingly, the organisation participates in a wide variety and range of activities to encourage governments, industry and the general community to take up the results of its research.

These activities include the traditional publication of research results, the use of industry seminars and secondments, using field days to demonstrate new techniques and approaches, participation in government committees and policy development processes, participation in industry and academic meetings and seminars, preparing popular publications, and so on.

An important part of technology transfer functions can be to seek intellectual property (IP) protection and then to enter into licensing agreements with firms wanting to exploit the IP. CSIRO is able to do this because it works at the early stages of the innovation process and can gain broad patent protection. Bundling the IP rights with the technology can provide an attractive package for technology transfer. The provision of exclusive rights to the technology decreases the risk of investing in it. Moreover, the return to CSIRO on its investment in technology development (through royalty payments) helps prevent the free rider problem. This approach of packaging IP rights with technology can also help avoid good technologies lying dormant because no firm is prepared to take the risk of investing in them.

One very important way in which CSIRO transfers technology is by making its expertise and research capacity available to other parts of the innovation system. In particular, CSIRO provides research, consultancy and technical services to government, industry and other customers on a fee for service basis.

In providing these services CSIRO promotes the national interest in many ways. For example, CSIRO information, advice and services may help government and its agencies better manage the environment, either directly or by putting in place appropriate policy or regulatory frameworks. Or they can help Australian firms increase or maintain their competitiveness, create employment opportunities and generate exports. (Attachment 3 provides examples of these services.)

Working with the proposed or potential end users of the research from as early in the development of the project as possible is one of the most effective ways of ensuring a path to adoption. Responding to market pull will always be easier than having to adopt a technology push approach.[53] This is not only because in responding this way it is certain that a market demand exists; it is also because working with the end user makes it possible to tailor the research solution to their technical, financial and other capabilities. This can reduce the need for additional work and re-engineering. It can also impose the discipline of practical requirements as distinct from the possibilities of scientific opportunity.

Discussions of technology transfer often concentrate on transfer to the private sector. However, the same considerations apply when the research customer – direct or indirect is government. CSIRO performs much research that has implications for government and that can best achieve impact by informing government policy development and programs. As a statutory authority, CSIRO employees are commonwealth officials. This places them in a privileged position with respect to government access. Direct participation in government processes such as interdepartmental committees, ministerial briefings, and departmental processes places CSIRO in a position of influence not available to university researchers, for example.

One of the ways in which CSIRO has worked to build on this advantage is through developing and strengthening its social science expertise. This allows it to bring together a broader disciplinary base that can help the science address more directly the increasingly complex questions that government wants answered. For example, CSIRO has recently established the CSIRO Integration Network. This will focus on the economic and social skills that complement the organisation's traditional science and technology strengths to help provide the integrated knowledge solutions that governments need.

[53] The use of this terminology is not meant to imply that any knowledge transfer responds to a single 'push' or 'pull' trajectory. In reality, transfer involves multiple separate operations and interactions that involve an understanding of both scientific possibilities and market needs.

As discussed earlier, CSIRO's basic operating principle is the need to maximise the benefits of its work. It offers some services to its customers on a full cost recovery basis, with the customer retaining all intellectual property. The firm and the nation benefit from the improved business performance that comes from using the intellectual property. In other cases CSIRO enters into co-investment agreements in which the customer and CSIRO both contribute to the cost of the research and share in the benefits that result.

In these cases Australia benefits not just from the improved performance of the customer, but also from the increased resources that CSIRO receives from its share of the return on the research investment. This enables CSIRO to build its own capacity additional to the support it receives from government and helps the organisation contribute even more to the welfare of Australia. An earlier section of this paper has already discussed the importance of this co-investment approach in helping Australian business, especially SMEs, cope with the technical and commercial risks of research. It plays an essential role in strengthening Australia's overall innovation system.

Technology transfer also includes what are sometimes more narrowly defined as 'commercialisation' activities. In particular these include the patenting and licensing of research funded by CSIRO and the use of spin-off companies to develop business opportunities originating in CSIRO research and capabilities. These often require a technology push approach. One reason for this is that CSIRO's research is often attacking problems and issues that are not yet on the horizon of those who need to know about them. CSIRO's role is not just to respond and react to existing problems; its responsibility is to look ahead beyond the immediate vision of industry and other research users.

One problem with working ahead in this way is that the domestic innovation system might lack the ability – or not have the inclination – to make use of the technologies and solutions that CSIRO might develop. This can happen for a range of reasons – from a lack of appropriate technical or management skills, an inability to obtain the necessary finance, risk aversion, and so on. The 'absorptive capacity' of the Australian innovation system for new technologies may well be less than that of other countries, in part because of the size structure of Australian firms, already discussed.

Because of the research domain in which it operates, CSIRO has a significant concentration of commercialisation and technology transfer expertise. In working to strengthen the particular role that it plays in the national innovation system, CSIRO has put more resources into strengthening and refocussing these business development and commercialisation activities. This has involved increasing the number of people working in these areas and further developing the organisation's skills base, in part by recruiting new staff with highly specialised skills.

In particular, CSIRO has capabilities in areas such as specialised legal skills, marketing and venture finance that go beyond those available in many other parts of Australia's innovation system if only because the scale of CSIRO's operations facilitates a degree of specialisation and concentration that most other research organisations cannot justify. This concentration of effort and expertise helps to strengthen not only CSIRO but Australia's science, business and other research user links.

Technology transfer is not a simple process and the avenues to application can vary significantly from one technology to another or one sector to another. One size does not fit all and detailed analysis is necessary to determine which approach is most likely to be successful in any particular case. This is an area of activity in which it is important to be creative and to use whatever works. In some cases this might involve working with business, individual firms or government. In other cases it is possible to go directly to the general community. One very successful example here is the way that *CSIRO's Total Wellbeing Diet* book has served to transfer the results of scientific research, in a very digestible way, directly to the individuals able to benefit from the research.

National Research Flagships – an initiative of CSIRO

CSIRO's Flagship initiative provides the most advanced, obvious and concrete manifestation of the organisation's efforts to increase the relevance and impact of its research. Flagships demonstrate a deliberate intention to change the way in which CSIRO operates and they provide an explicit response to changes in the global innovation system. In particular, they recognise and respond to Australia's place in the world. The rapid economic and other changes taking place in Asia mean that Australia needs to achieve critical mass research programs and to identify niche areas within which it can build on its capabilities to maintain and create the opportunities necessary to support its continued economic development. This is what flagships are about.

CSIRO is currently managing six flagships, each of which has an explicit goal that provides the focus for its management:

- Energy Transformed
    - *To halve greenhouse gas emissions and double the efficiency of the nation's new energy generation, supply and end use, and to position Australia for a future hydrogen economy*.
- Food Futures (originally named Agrifood Top 5)
    - *To transform international competitiveness and add $3 billion annually to the Australian agrifood sector by the application of frontier technologies to high-potential industries*.
- Light Metals
    - *To lead a global revolution in light metals, doubling export income and generating significant new industries for Australia by the 2020s while reducing environmental impact*.
- Preventative Health
    - *To improver the health and wellbeing of Australians and save $2 billion in annual direct health costs by 2020 through the prevention and early detection of chronic diseases*.
- Water for a Healthy Country
    - *To achieve a tenfold increase in the economic, social and environmental benefits from water by 2025.*
- Wealth from Oceans

- *To position Australia by 2020 as an international benchmark in the delivery of economic, social and environmental wealth based on leadership in understanding ocean systems and processes*.

The identification of these six areas was the outcome of a long and intensive process involving the collection of data, its analysis and widespread consultation with other researchers, business and government. This process took into consideration not only domestic capabilities, issues and challenges but also what was happening overseas.

The significance of Flagships goes beyond that of the effort and processes that CSIRO used to develop them. This is because their focus on outcomes provided some of the impetus for the development of the performance management and evaluation techniques already described. The focus throughout their development has been on impact and a recognition that impact depends on the activities of partners outside the research system.

While CSIRO's skills and experience in managing large scale projects have developed over time, the Flagships present a major leap forward. Flagships represent more than an increase in scale and the development of more effective research management techniques. They also demonstrate an increased commitment to partner with other research performers and with the users of research outputs. The Flagships are ambitious, integrated programs of coordinated activity directed towards achieving agreed goals. Their purpose is to help shape the future of an industry or sector within Australia or to address a major national challenge. They go beyond research in that their planning and implementation integrates the capture and application of the research results within Australia.

In developing flagships the approach has been to identify opportunities that require a research solution, rather than to search for problems that existing research strategies might address. Apart from anything else, this has meant that the research capabilities necessary to address the problem might lie outside CSIRO. This in itself creates the need for the partnerships and linkages that lead to additional synergies. The $97 million Flagship Collaboration Fund is one of the mechanisms supporting this approach and is helping to create long term collaborative partnerships that will produce outcomes that none of the partners would be able to produce alone.

Flagship programs are some of the largest directed research efforts ever mounted in Australia. They depend on the highly sophisticated research management skills that CSIRO has developed through its evolving experience with ever larger and more complex programs; and focus significant resources on areas of national importance. Their development has required partnerships and cooperation.

It is important to recognise that two quite different kinds of external partnerships are critical to Flagships meeting their goals:

- collaborative relationships with other research agencies:
    - these range across the public/private spectrum with collaborators including universities, government agencies at federal and state levels, publicly funded research agencies and companies; and
- relationships with delivery partners (those who convert the research outputs produced by the Flagships into outcomes in the economy, society or the environment).

The outcomes that Flagships strive to achieve require all parts of the innovation system to work together to capture and apply the research outputs. Moreover, the scale and intensity of the effort CSIRO put into developing and coordinating these programs, and will continue to put into their management, will help reduce the risk to the businesses that become partners.

The considerable background work and market intelligence that has led to the identification of the priority areas is often beyond the capabilities of the other partners, including business partners, yet plays an important part in reducing the commercial risks of participation.

The Flagships are the centrepiece of CSIRO’s revised value proposition. They are based on:

- tackling Australia’s biggest national challenges
- delivering high impact, high quality science in pursuit of those challenges
- delivering effective outcomes by working with partners
- achieving long-term goals by a combination of short, mid and long-term science outputs
- introducing a new way of doing science (multidisciplinary, multi-agency, transformational science to make a difference)
- investing significant resources from CSIRO and its Flagship partners
- delivering high standards of accountability through rigorous governance controls.

To ensure that they focus on meeting this value proposition, all Flagships develop technology roadmaps that outline the technical developments necessary to achieve their long term goals. They also develop engagement roadmaps that show the relationship developments (with commercial partners, research collaborators, end users and others) necessary for the successful delivery and uptake of flagship outputs.

Each Flagship has established an advisory committee, whose members are largely external and drawn from relevant industry/stakeholder groups. These committees provide guidance to the Flagship Directors on maximising portfolio effectiveness. They also provide strategic advice about possible Flagship investment and commercialisation/ technology transfer opportunities and options. Members of the advisory committees also act as advocates for the Flagship in various forums.

At this stage of their development, Flagships are still primarily CSIRO entities. CSIRO retains overall responsibility for determining their strategic directions (in consultation with external stakeholders) and provides the majority of the funds invested in them, as well as most of the other resources involved. A CSIRO Flagship Oversight Committee plays a major role in their governance by recommending resource allocations, undertaking performance reviews and directing the overall portfolio of research. Nevertheless, the intention has always been that as they develop, and as new Flagships become necessary, the approach will increasingly be one of 'Team Australia Flagships', rather than just CSIRO Flagships.

In summary, Flagships have helped CSIRO focus its activities on major national goals closely aligned with the National Research Priorities (and the adoption of a 'fast fail' approach to project management has ensured that they remain appropriately focused).[54] They have received the largest redirection of CSIRO funding in the organisation's history. They have emphasised the importance of partnerships, not just for research purposes but also for delivering impact to the economy, society and environment. And they have pioneered the sophisticated use of the Program Performance Framework as a structured approach to the setting, pursuit and achievement of goals.

Attachment 8 provides information on some of the impacts that the flagships have already made. More generally, in 2004-05 alone, flagships lodged 30 patent applications, signed nine major contacts (each over $500 000), received $16 million in partner contributions and published more than 200 scientific reports and publications. Perhaps more important than all of this is the progress they have made towards realising their longer and shorter term goals.

Australian Growth Partnerships

Although not on the scale of Flagships, CSIRO has developed and is continuing to develop a potential model for more effective collaboration and technology transfer with small business. This is the Australian growth partnerships model. This recognises that small businesses that have been effective in taking to market and profiting from one technology clearly have what it takes and have a good chance of successfully commercialising additional technologies. They have gained experience, developed networks and have existing infrastructure, as well as appropriate management structures. However, because of the risks involved in trying to do something new again, they may be reluctant by themselves to expand into new areas.

An Australian Growth Partnerships' competitive program would provide funds directly to SMEs that already have a track record of success in technology commercialisation. The selected firms would use this support to collaborate with Australian research providers, such as CSIRO.

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[54] As an example, the Energy Transformed Flagship has replaced an 'intelligent transport stream' by a 'transport fuels stream' which responds to escalating oil prices and Australia's oil resource rundown. The new stream will have a greater impact in helping achieve the goal of reducing transport emissions. The Light Metals Flagship has 'fast-failed' fourteen projects for not meeting the technical, economic or partnering risks in the path towards the Flagship's goals.

The aim of the program would be to transfer technology to the SMEs and to provide the technical assistance the SME would need to commercialise the technology. If the SME were to be successful in commercialising the technology it would repay the funds received from the program. If participation did not result in successful (profitable) commercial outcomes, no repayment would be necessary.

Evaluating CSIRO's impact

CSIRO's outcome reporting framework

Over the last five or so years, CSIRO has made significant changes in the ways that it operates to provide a much stronger focus on outcomes. These changes are already starting to take effect. However, it would be misleading to think that CSIRO has had little impact in the past. Recent initiatives are aimed at making what was already a very successful record of converting research to public benefit even more successful.[55]

CSIRO has used and still uses a variety of mechanisms to measure and assess the benefits that its research produces for Australia. Its formal reporting uses a framework consisting of four outputs and nine outcomes.

The four output categories broadly describe the types of research products and services that CSIRO delivers. These are:

- new/improved technology or management system;
- advice or 'catalyst services' for policy or business;
- new/improved intermediate or final products; and
- new knowledge or skills.

Applying these outputs can result in nine different types of impact on Australia's economy, environment and society. These impacts provide an indication of the extent to which CSIRO is effective in achieving the outcomes towards which it is directing its research.

The application or use of CSIRO outputs contributes to *Innovative and Competitive Industrie*s through:

- lower (more competitive) unit production costs;
- improved quality goods and services; and
- new products, services or businesses.

The application or use of CSIRO outputs contributes to *Healthy Environment and Lifestyles* through:

- improved human health, safety and wellbeing;
- reduced pollution; and
- improved environmental health.

The application or use of CSIRO outputs contributes to A *Technologically Advanced Society* through:

- development of skills (enhanced human capital);
- informing policy (cost-effective public programs or institutions); and
- reduced risk (economic, social or environmental).

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[55] Brad Collis' book *Fields of Discovery* provides a broad overview of CSIRO's contributions to Australia over the last 50 years.

While this framework is comprehensive, its language tends to highlight the tangible impacts that CSIRO produces rather than the intangible but very real effects that arise, for example, from its reputation or the international linkages that this can support. These intangible impacts are not inconsequential. For example, having a good reputation generates the trust necessary to attract high quality partners in major research programs such as the national research flagships. This increases the likelihood of attracting the investments necessary to convert CSIRO inventions to the innovations that capture the value of the science. As the level of investment for innovation is often considerably greater than that necessary to conduct the research, a major flow on from the intangible direct impact of a good reputation can be a significant increase in business investment and innovation.

Similarly, the outcome descriptions encompass, but do not make explicit, the inherent value and cultural significance of advancing knowledge, independently of any instrumental effects; or the importance of maintaining and developing capabilities – the insurance value of developing an ability to address problems or take up opportunities as they arise. In this context it is important to recognise that the development and maintenance of capability to provide a capacity to respond is usually an indirect outcome of other activities, not something that receives separate funding.[56] For example, the Australian Animal Health Laboratory will play a vital role should there ever be an outbreak of foot and mouth disease in Australia or an influenza pandemic. But it is not idle pending such a crisis and work using the facility is producing benefits beyond its 'insurance' value.

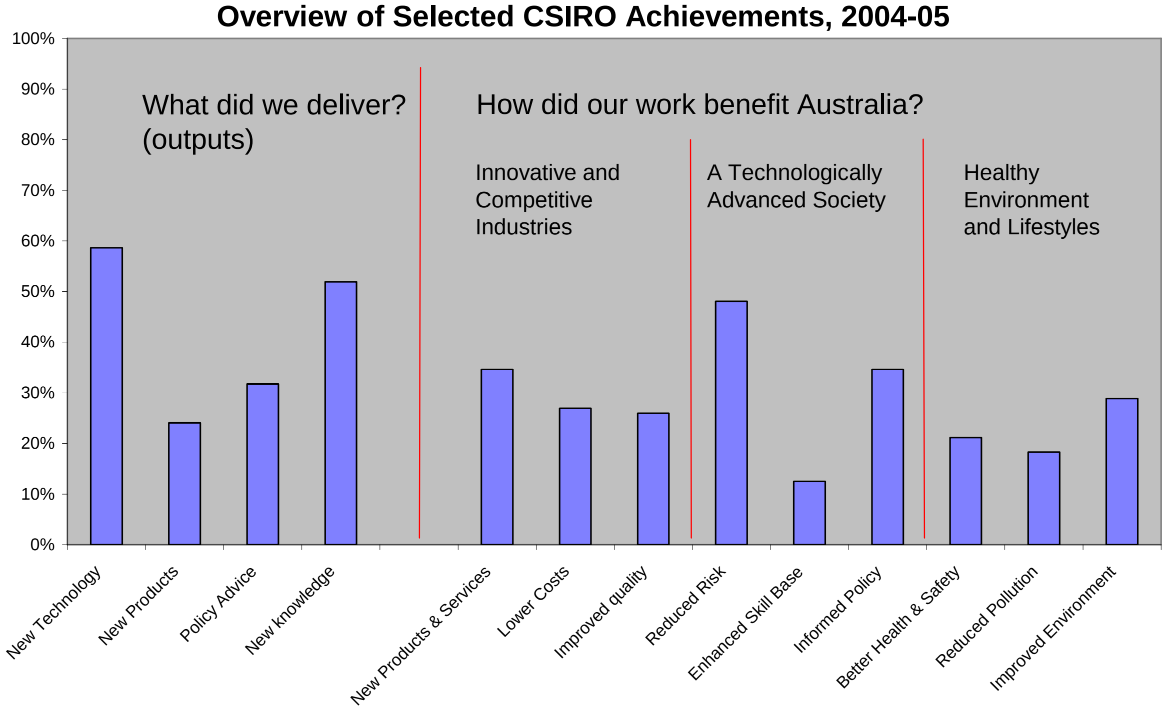
Another area that the framework does not stress is the impact of CSIRO and its activities on the general community. Given its status as a government owned organisation with a long record of achievement, CSIRO is often the first point of contact for members of the general public seeking information about science or its implications. CSIRO plays a major public awareness role, for example responding to over 35 000 inquiries from the general public each year.

Stories involving CSIRO science feature in around 12 000 news or feature items in print, radio and the media each year. Having a trusted, independent research organisation facilitates public debate about science and can help generate the 'licence to operate' that is important for all parts of Australia's research system, not just CSIRO.

To illustrate how the reporting framework operates, the following data are taken from CSIRO's 2004-05 annual report and Attachment 9 lists examples of specific achievements under each heading of the framework.

In total, the Annual Report described 104 outputs and their associated outcomes. The following chart illustrates the allocation of all 104 across the output and outcome categories.

[56] However, it is a factor taken into account in science investment process.



The chart shows, for example, that around 60 per cent of the achievements described in the Annual Report text involve delivery of 'new technology' and approximately 30 percent involve the delivery of 'policy advice'.

Any one output can, and frequently does, produce a number of different types of impact. The chart allocates each of the reported achievements to a maximum of two output categories and a maximum of three outcome categories. (Percentages therefore add to more than 100%). Given the nature and breadth of some of the achievements, the allocation process necessarily involves an element of subjective judgement.

Measuring CSIRO's impact – the past

CSIRO has used a variety of means to help assess and evaluate its impact and to ensure that the benefits that it provides to Australia exceed the level of the government's expenditure in the organisation. While none of these techniques is complete in itself, they can all demonstrate that CSIRO is having an impact – even if they are not all able to quantify this impact. Moreover, the information provided by different techniques can be complementary and together provide a more rounded assessment than any can individually.

Indicators

Input indicators can demonstrate the way in which CSIRO is responding to the government's aim to achieve economic and other impacts more directly and more quickly. For example, they show that CSIRO directs 84 per cent of its expenditure to national research priorities. Similarly, figures showing trends in the value of commercial contracts show the extent to which the organisation is devoting effort into areas that the private sector has identified as being important enough to invest in.

Other relevant data can show the proportion of the total research effort going to basic, strategic or applied research and into experimental development. While none of these data provide a detailed measure of economic outcomes, they can help illustrate the extent to which an organisation is directing resources to shorter term rather than longer term benefits.

Output indicators (such as numbers of scientific publications, citations, patents, etc.) can provide a broad indication of productivity. Because it is possible to standardise them in various ways (eg according to the number of staff or level of research expenditure) they can provide a basis for benchmarking studies. However, as remarked earlier, benchmarking may not make much sense unless the organisations subject to benchmarking comparisons have similar roles and responsibilities and are aiming to achieve similar outcomes.

Some indicators can provide a proxy measure of the quality of an impact. This is clearly the case with citation data for science. Other relevant indicators in this area include the number and proportion of CSIRO officers awarded prizes or otherwise honoured by their colleagues, for example through election to prestigious positions on international bodies. These not only demonstrate the high esteem in which CSIRO scientists are held, they may also provide direct practical benefits through access and influence.

The data provided below provide some indicators that demonstrate CSIRO's performance and impact. They show the kinds and the extent of contributions that CSIRO is making to Australian science and how the output levels are increasing.

- CSIRO ranks in the top one per cent of world scientific institutions in 13 of 22 research fields (based on the Institute for Scientific Information data on total citations of publications)
- CSIRO has the second highest citation rate of any Australian organisation (after the ANU) and the rate at which its citations level is increasing is faster than that both the Australia and international benchmarks.

Summary data for Australia, CSIRO and selected universities, ranked by citations per paper				
Institution (3 292 total institutions)	Papers total	Total citations	Citations per paper - average	Citations per paper – increase
ANU	16 475	184 857	11.22	0.36
CSIRO	**15 344**	**160 460**	**10.46**	**0.59**
U. Melbourne	21 076	211 705	10.04	0.55
U. Sydney	23 142	219 609	9.49	0.57
Monash	15 147	141 885	9.37	0.67
U Queensland	19 859	181 649	9.15	0.74
U NSW	17 134	151 690	8.85	0.68
U WA	13 004	114 816	8.83	0.68
U Adelaide	10 859	94 543	8.71	0.45
Australia	**232 254**	**2 109 588**	**9.08**	**0.47**
World			**8.62**	**0.35**

- CSIRO produced over 4 000 scientific publications in 2005, and also transferred know-how through over 10 000 client reports.

Number of Publications by Type	2002	2003	2004	2005
Journal Articles	1,686	1,836	1,858	1,945
Books/ Chapters	223	240	270	238
Conference Papers	1,142	1,428	1,713	1,852
Technical Reports	240	442	280	620
Client Reports	10,486	8,451	8,251	10,774
Total (excl client reports) per RS/E*	2.11	2.49	2.59	2.92

* RS/E = Research Scientist/Engineer @ June 30

- CSIRO is the largest single participant in the Cooperative Research Centre (CRC) Program (participating in 49 of the 69 centres, as at 30 June 2005)
- Worldwide, CSIRO is involved in over 900 current or recently completed research activities, working with leading scientific organisations and firms in 75 countries including the United States, Japan and Europe, and with developing countries, especially in Asia
- CSIRO offers more than 50 specialised technical and analytical services. These include analyses for air pollutants and satellite imaging of natural resources through to fire testing of materials and diagnosis of exotic animal diseases
- CSIRO is Australia's leading patenting enterprise, holding over 4 000 granted or pending patents

IP Production	2002-03	2003-04	2004-05	2005-06
New Inventions	92	89	79	134
Total Inventions	779	754	745	780
Granted Patents	2,002	2,079	2,048	2,113
Live Patent Cases	3,965	3,961	3,919	4,084
Live Patents per RS/E	2.50	2.48	2.46	2.56

* RS/E = Research Scientist/Engineer @ June 30

- CSIRO Education involves over 700 000 students, parents and teachers each year in activities that encourage appreciation of science.
- CSIRO jointly produced the *Totally Wild* science TV program, which has a viewing audience of over 400 000 each week.
- There are nine CSIRO Science Education Centres across Australia. These provide hands-on classes for more than 260 000 students each year.

Another interesting indicator of the impact that CSIRO has is that other organisations use their collaborations with CSIRO as an example of their own commitment to innovation. As an example, in the recent Business Council of Australia report *New Concepts in Innovation*, IAG, Holden and DuPont all make specific reference to their collaborations with CSIRO.[57]

Anecdotal

At the most basic level, it is possible to point to economic benefits that flow directly from research projects. It is possible to do this without detailed analysis but simply to note that a particular technology was a direct outcome from a particular research project. CSIRO's annual reports include large numbers of important outcomes from the previous year's activities. (Attachment 9 provides the titles of some examples). While a long list can be impressive, it does not provide any quantitative indication of the level of economic benefits or of what level of additional investment was necessary to achieve them. However, it does identify some of the economic benefits that research is producing and can help illustrate their variety.

Case studies

Case studies can follow through individual projects to explore the ways in which research produced an economic outcome. While they operate at the micro-level and the impacts they identify relate only to the particular project or program they examine, case studies do have many advantages. In particular, they can help identify the players beyond the research performers and help identify the total costs of converting an invention into an innovation. Case studies are necessarily retrospective and can often depend as much on anecdote as on data, not least because of the complexity of the process and the diverse array of players usually involved.[58] However, they can play an important role in developing a better understanding of innovation processes.

Cost benefit analysis

Cost benefit cost analyses also operate at a project level and are often less rich in detail, although richer in quantitative data, than case studies. The objective of a benefit cost analysis is to identify the full costs of the research and to assess in detail the economic value of the benefits that have flowed from the research or are projected to do so. A single study can be expensive and this limits the extent to which it is possible to use them.

The quality of this kind of analysis can vary enormously. For example, some analyses take into account only the cost of the research and ignore the often greater financial investments that come from those using or commercialising the research. There can also be significant differences in the extent to which the analysis takes into account the full range of benefits that flow from the research or concentrate on the direct commercial outcomes. Some benefits can be difficult to quantify or to attribute in an unambiguous way to the research that may have produced them.

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[57] DuPont notes in this report that its technology alliance with CSIRO had generated more than 50 worldwide patents in just 10 years, providing huge possibilities for commercialisation of products driven by Australian research.

[58] A detailed case study of interest is: Mark Matthews and Bob Frater (November 2003): *Creating and exploiting intangible networks: how Radiata was able to improve its odds of success in the risk process of innovation*. A case study prepared for the Science and Innovation Mapping study of the Department of Education, Science and Training.

The assumptions made in conducting a cost benefit analysis can make a big difference to the conclusions, especially when looking at projected rather than retrospective benefits. Attachment 4 summarises the conclusions of some past cost benefit studies of CSIRO research.

Commercialisation surveys

Case studies and cost benefit analyses are necessarily selective and local, in that it is necessary to choose particular examples for study and it can be difficult to extrapolate any conclusions beyond the particular project or organisation under study. In contrast, surveys can provide a more comprehensive and more balanced set of data. However, by themselves surveys usually address only part of the economic impact equation.

Commercialisation surveys normally collect data relating to spin-off companies, patents and other IP rights applied for or granted, and licensing income. They may include customer data, showing the number of customers and the size of contracts.

These surveys can provide a comparable set of data from different organisations. However, the data set does not take into account the different roles and responsibilities of these organisations or the different commercialisation strategies that they might use, not least because of the different sectors for which they perform research. Neither do they take into account the fact that the preferred commercialisation strategy might not involve any of these activities but rely, for example, on trade secrets. Moreover, commercialisation surveys generally do not examine the cost side of the equation and either ignore (or do not assess) the actual economic impact of each organisation's activities. (In most cases the economic impact of a technology would far exceed the licensing fees going to the inventor, or even the improved financial performance of the firm using a technology.) Maintaining IP rights, for example, can impose a significant cost if there is no customer interested in using those rights.[59]

These surveys also miss the economic impacts that can be more difficult to measure, such as those relating to the impact of the research on skills, policy advice or the very many uses of research that occur without the need for explicit commercialisation vehicles.[60]

A particular problem with such surveys is that they can influence the behaviour of organisations covered by the survey such that they favour strategies that increase the financial return to the organisation as distinct from those which increase the economic return to the nation.

[59] When the AUTM (Association of University Technology Managers) surveys started in the US, an unforeseen consequence was a major increase in patenting activity and an increase in patenting costs but with no commensurate increase in genuine commercialisation behaviour. The performance metrics were distorting organisational behaviour because they were at best partial indicators. Patent portfolios became a symbol of performance in themselves.

[60] For example, the major economic impact of most university research probably arises from the transfer of skills and knowledge that takes place as students move out to work in the wider community.

For example, using commercialisation surveys to measure performance can encourage patenting and the granting of exclusive licences in situations when the best return for the nation might come from the rapid and free diffusion of the technology to those able to use it. Or they might encourage the formation of spin-off companies that face all the attendant risks of a new business when the most certain path to market might be through an existing business. This can be of particular significance for organisations performing research in sectors such as agriculture or in public good areas such as environmental management.

DEST has commissioned a consultant to conduct the 2006 commercialisation survey and CSIRO's contribution to this survey is shown below.

	2000-01	2001-02	2002-03	2003-04	2004-05	2005-06
	$ million					
DEST Survey categories:						
Running Royalties			10.365	7.699	12.452	18.971
Cashed-in equity			0	3.647	4.478	2.618
All other types			3.424	4.296	2.600	1.537
Total (As per DEST survey)			**13.789**	**15.642**	**19.530**	**23.13**
Value of other equity holdings booked by CSIRO in year (not cash transaction)			0.67	8.5	1.0	9.3
Value of all research commercialisation equity holdings held at 30 June			5.861	10.115	9.269	25.772
LOA income paid to other institutions[61]:			0.696	1.229	2.772	4.598
Estimated total product sales from licensed technology				718M	1,300M	1,300M

[61] Additional to running royalty figures above

Stakeholder surveys

It is possible to survey customers and other stakeholders of research-performing agencies to assess stakeholder views of the economic importance of the agency. The responses will often be qualitative, anecdotal and unsophisticated in an economic sense. Nevertheless, stakeholder perceptions of the economic impact of an agency can be valuable in a political context. Such surveys can also help identify ways of increasing economic impact by improving linkages and changing perceptions.

CSIRO's Customer Value Survey provides some indicative data along these lines, at least for the research that the organisation performs for its commercial customers. The most recent surveys demonstrate that customers continue to value CSIRO's science excellence but their feedback has also identified areas where CSIRO could do considerably better, for example in contract negotiation, cost, and intellectual property management.

Complementing the customer survey is a CSIRO national brand positioning and performance evaluation. CSIRO commissioned this to independently survey 1 020 stakeholders from government, business and the general community. Among the findings were that the public has a very good awareness of CSIRO and that overall CSIRO ranked ahead of such Australian 'icons' as Telstra, the ABC, Qantas, BHP-Billiton and the Macquarie Bank.

Awareness of CSIRO was also strong relative to that of other Australian science and technology organisations. Given CSIRO's role in performing research that can have impact by informing policy development, it is important that government policy makers agreed that CSIRO is responsive and proactive in engaging in the policy process, even though they saw room for CSIRO to strengthen its engagement and develop a better understanding of the policy process.

Measuring CSIRO's impact – the future

As is clear from the previous discussion, CSIRO has long had an interest in measuring its economic, environmental and social impacts with a view to improving its own performance. However, there are clearly methodological issues that can limit impact assessment, not least because many impact measurement tools work at the level of individual projects. It is not possible to extrapolate from these to the impact of the whole organisation, especially as some of the more quantitative techniques can be expensive to use. A further difficulty is that CSIRO produces scientific outputs but other parts of the innovation system have to take and use these to create impact, sometimes making it difficult to determine what proportion of the impact to attribute to CSIRO.

There is also the complexity that while measuring economic impacts can be relatively straightforward, at least in principle, measurement of environmental and social impacts can be much more difficult. Not least this is because different members of the community might view the same outcome in contrary ways.

Environmental research that leads to the closure of a fishery might have an immediate negative economic impact, even though in the much longer term it will preserve a resource that might again become available for use. Research that suggests the need to stop grazing in the high country to preserve its biodiversity and conservation values might receive a very different response from graziers and conservationists. Issues relating to water management can have many rival stakeholders each with their own, sometimes competing, value systems, who judge the outcomes of the same research, and its potential application, in very different ways. A program to reduce obesity in children might be expensive to implement but not have any serious economic benefits for 30 or 40 years.

Because of these and other complexities, CSIRO has commissioned ACIL Tasman to help CSIRO review the methods available to analyse CSIRO’s impact on economic, environmental and social outcomes. The consultants have assessed the strengths and weaknesses of the various methodologies for measuring impact. Flowing from this work they have proposed a way to assess CSIRO’s recent performance using the most appropriate suite of methodologies, given the areas in which CSIRO is active.

As a result of its preliminary analysis, ACIL Tasman has recommended an evaluation framework that expands on existing approaches by adding options valuation to the existing techniques. This has the potential to capture the less tangible and measurable forms of value by taking into account the inherent options created by CSIRO planning, research and infrastructure. Attachment 10 provides a brief explanation of the approach CSIRO will be using and CSIRO will provide to the commission a copy of the final report from this exercise when it becomes available.

CSIRO responding to impediments in the national innovation system

The terms of reference for the study require the commission to identify impediments to the effective functioning of Australia's innovation system and to identify any scope for improvements. The terms of reference also list a number of processes that are important for the effective operation of the system: knowledge transfer, technology acquisition and transfer, skills development, commercialisation, collaboration between research organisations and industry, and the creation and use of intellectual property. Problems with any of these processes might limit the outcomes the system is able to achieve.

This submission has already described how CSIRO assesses the complex and changing innovation environment and has responded to this by moving to ensure that path to market or to impact issues play a central role in its planning, management and evaluation processes. An associated initiative has been to make it easier for business to work with CSIRO, for example by simplifying contracts.

One of the most important elements of CSIRO's overall strategy has been to engage with relevant stakeholders, including the potential end-users of research, as early in the planning processes as possible; and to maintain this engagement. This not only helps to steer the research and keep it focussed on what will be useful, it also helps develop among stakeholders the understanding and capabilities that are necessary to make use of the research. Nevertheless, there are clearly some factors that can make it more difficult than it should be to generate the impacts that are possible. This section of the submission describes these from a CSIRO perspective that draws heavily on the organisation's recent experiences.

Different perspectives

The reality of discussing impediments is that different parts of the innovation system have their own perspective on possible limiting factors, depending on their own roles, responsibilities and stakeholder interests. Cultural differences between different components of the system can impede effective communication and present negotiation hurdles.

The value which a university sets on intellectual property may be quite different from that a business might use, for example. This can happen when the research provider does not understand the level of risk or amount of additional investment that a potential innovator can face in using their research. In performing contract research, an organisation may not recognise the value of the background intellectual property that has gone into formulating the problem they are addressing. Consequently the research organisation might seek IP rights that their customer finds outrageous. These kinds of misunderstandings and differences can add significantly to the transaction costs of developing the partnerships necessary to create impact. In extreme circumstances they can result in an impasse.

The closer the culture and approach of the collaborating parties, the less likely such differences are to occur. Collaboration between businesses can be easier than collaboration between a business and university because of their shared objectives and cultures. A broader based education and more diverse career paths might help to develop a better understanding, on all sides, of the value of the contributions made by different parties to the innovation process.

Venture capital

Another example of the problem caused by different perspectives is that it is not uncommon for technology producers to complain there is a lack of venture capital, while at the same time the venture capital industry bemoans the lack of business ready projects. This might indicate a genuine problem, such as the lack of funding to develop the outputs of research to the stage at which they become attractive to venture capitalists, given their current risk appetite. On the other hand it might simply reflect respective experience or knowledge levels on matters such as market opportunities, competing technologies and commercialisation costs. In many instances there may be no unambiguous way of resolving these differences of opinion, especially as the system is not static and the circumstances are often peculiar to individual cases. Benchmarking against other countries does not always provide a useful indicator, given the differences that inevitably exist between countries and the importance of local factors and capabilities.

While this is a vexed issue, CSIRO's perspective is that that there is a shortage of venture capital at the high risk end of the spectrum and that the level of investment government supported funds can make into any one firm may be too low. The government's announcement in its last budget of funding for a new round of Innovation Investment Funds might help alleviate this problem. However, there can be a tendency for such funds to move to the lower risk areas as they establish themselves. In part this might reflect a paucity of experienced entrepreneurs with the management skills and experience necessary to plan and develop new, technology based companies.

Dynamic nature of the innovation system

The innovation system is dynamic and operating within broader domestic and global environments that are themselves changing rapidly. This can make it difficult for potential innovators to be sure that they understand for example the regulatory environment applying to the markets they hope to enter. At a domestic level it may mean they are uncertain where to go for advice, what government support might be available, or where to go to access it.

Because the system overall is dynamic, the factors that in some way make it more difficult for publicly supported science to have impact also change. Moreover, there is no single path to impact and the impeding factors can vary significantly from one area of research to another, and for different types of science. An important implication of all this is that it is not possible or sensible to attempt any micromanagement of the innovation system. While it is important to address any factors that decrease the system's effectiveness or efficiency, this has to be done in a way that maximises the flexibility, responsiveness and development potential of the system.

Among other things, this means that a complex regulatory environment, including differences in regulations between states (such as moratoria on genetically engineered food crops), can create unintended consequences broader than the intent of the legislation. The intention should always be to facilitate the use of whatever options are most likely to succeed, rather than promoting particular innovation pathways above others.

Inappropriate performance measures

One example of the care that is necessary in managing the system is the way that the use of inappropriate performance measures can have unintended consequences. For example, patenting is expensive and unless a patent is part of a broad commercialisation strategy, maintaining a patent portfolio can be expensive without producing any returns. It is difficult to create a business around a single invention, so spin-off companies are not necessarily the best way to seek economic impact. Open communication can sometimes decrease impact when the necessary commercial strategies depend on secrecy. Licensing income provides a return to the IP owner but from a public policy perspective the technology might have had a greater economic impact if it had been freely available to anyone wanting or needing to use it.

The use of unnecessarily restrictive performance measures relating to particular paths to impact may be one reason why studies of innovation often conclude that intellectual property issues are a major cause for concern and identify approaches to the protection of intellectual property as a major impediment. While the valuation of IP rights will often be a source of conflict and can drag out negotiations, the issue for publicly supported science should be to achieve public benefit – and measuring the performance of organisations receiving public support in terms of particular impact pathways could have perverse results.

Working within a complex system requires sensitivity if measures intended to achieve better performance are not to have contrary effects.

Clarity of purpose

One consequence of the changes that have taken place in the innovation system is that the roles and responsibilities of its different components have become less clear. The application of similar performance measures to different parts of the system has exacerbated this.

Instead of clearly differentiated and specialised bodies, each making their own contribution to the innovation system and interacting with bodies that play quite distinct roles, the changes that have taken place have reduced diversity and specialisation. As discussed in earlier parts of the submission, increasing competition for funds, among other factors, has led different parts of the system to move into areas they did not previously occupy. Universities, once strongly focussed on their educational responsibilities, now have to pay attention to the economic impact of their research, even though the primary purpose of this research was formerly the pure advancement of knowledge, which supported and enhanced the educational experience they provided their students.

Many parts of the research system now perform a much wider range of research than was formerly the case. In particular, the level of service research – research performed for a particular customer or intended to achieve a particular (usually economic) impact – has increased.

Earlier parts of this submission have argued that Australia requires a diversity of research managed for different kinds of impact. It has also noted that research management processes may be quite different, depending on the kind of impact the research aims to achieve. Different kinds of research management require distinctive governance arrangements within the organisation using them. These governance arrangements need to reflect the primary purpose of the organisation and be sufficiently transparent to meet the organisation’s accountability requirements. Moreover, the accountability arrangements should also reflect the purpose of the research. Advancing knowledge requires a quite different accountability framework from that used for business research projects operating to tight timeframes and market disciplines.

These issues raise the question of whether the various components of Australia's research system have adopted new and appropriate management governance and accountability arrangements to reflect their changing research portfolios. CSIRO's experience is that developing and using the right kind of management processes in an appropriate governance framework has the potential to increase the likelihood of impact, increase the level of impact, and produce an impact more quickly.

An organisation performing research aimed at a variety of different kinds of impact may need to use different planning management and evaluation techniques for each type, in order to maximise the return on the investments it, or its funding bodies, make. The extent to which external stakeholders play a role in research planning (and the ways in which they exert influence) should vary significantly depending on the purpose of the research – but for some forms of research early engagement is necessary to achieve impact and governance arrangements have to allow for this.

There are different ways to address this issue. One would be for individual organisations to use a diversity of systems that reflect the diversity of their research portfolio. Another might be for different organisations to move back to their core responsibilities and to develop the systems that help it best meet those responsibilities. Another is for research funding bodies at all levels to take into account the processes internal to a research performing body when distributing funds, to ensure that the organisations receiving the funding will manage the research in a way that is most likely to achieve the impacts the funding body desires.

What is clear is that using research planning, management and assessment techniques that are inappropriate for a particular type of research can certainly act as an impediment to the research having impact – especially when the impact being sought is economic. Adopting more explicit requirements for research management and governance arrangements might help improve both the efficiency and effectiveness of Australia's research and innovation systems.

Australia's geographic location and economic structure

In considering impediments it is important to recognise some special problems that Australia has and for which there is no direct resolution. Australia's geographical location presents many opportunities for science (such as southern hemisphere astronomy or its endemic plants and animals) but its isolation from large markets can present problems in trying to maximise economic impact. This is not only because producers like to locate their major activities close to their markets, it is also because large markets can support a diversity of suppliers that allows the development of network effects. Ideas for innovation most often originate from leading edge customers and suppliers. A diverse customer and supplier base facilitates this and makes it easier for people with specialised skills to move around, passing on their knowledge and gaining new skills and knowledge as they go. Clustering, concentration and critical mass build on each other to increase the demand for innovation and the capacity to absorb it. These issues are especially important with respect to the manufacturing sector.

Australia's relatively small manufacturing sector, with its predominantly small firms distributed over a large land area, presents fewer and more difficult opportunities for certain kinds of impact than found in larger, more heavily industrialised countries with large firms. A further issue is that Australia's small market means that in many cases it will be necessary for firms taking on new technologies to export if they are to be successful in recovering their innovation investments. A large potential market can help reduce the commercial risks of innovation. However, building up the capability to export if it does not already exist is an additional expense and risky in itself.

Impacts of globalisation

Globalisation is serving to intensify many of the problems that Australia faces in converting science to innovation. High rates of economic growth in the region and an ever higher investment in science by other countries is creating an increasingly competitive environment. Scientists move around the world freely and as regions such as the European Union set themselves high target figures for the proportion of GDP they intend spending on research, the demand for scientists is increasing. As regional capabilities build and expand, research is as likely to move offshore as is manufacturing. As trade becomes increasingly free of tariff and other distortions, it becomes more difficult for Australia to compete in certain areas, given the economies of scale available to large overseas countries.

These impacts of globalisation make it all the more important for Australia to allocate its available resources to those niche areas in which we have a strong and effective capability. We need to concentrate our effort into areas where the nature of the sector provides a realistic possibility that Australia can be successful. The analysis that CSIRO carries out through its Flagship development, science investment and related processes is focussed on the identification and definition of such areas and on building on our well defined strengths and opportunities. However, identifying potential areas is not enough – it is also important to build up in these areas a critical mass of effort and to ensure that the effort goes not just into the science. Apart from anything else, it is necessary to ensure that we have access, in Australia, to the scientific infrastructure and services necessary to support businesses building on the outputs of research.

Absorptive capacity

Earlier parts of this submission have discussed how Australia's industrial structure has created the need for public sector performance of some kinds of research that in other countries the business sector might perform. However, there would be no point in the public sector performing this research if the business sector lacked the capacity to make use of it. Absorptive capacity can reflect a wide range of issues, some of which may be internal to the firm or sector, some external. They can include the availability of the necessary skills (managerial as well as technical), finance issues, risk management techniques, entrepreneurial culture, investor attitudes, and so on. Government support can help address some of these issues but CSIRO's perception is that many SMEs struggle to understand the range of government programs available to them.

Absorptive capacity becomes a particular problem when dealing with technology developed through the recognition of scientific opportunities – ‘technology push’ rather ‘than market pull’. CSIRO works to increase the absorptive capacity of industry through the mechanisms previously described – early engagement, working within the capabilities of research users, risk sharing through co-investment and a broad spectrum of communication activities. Despite this, most players would agree that action is necessary to improve the absorptive capacity of Australian industry, especially of the manufacturing sector. This is not because potentially important research outputs remain unused. Rather it is because technical innovation provides the base for competitiveness and because Australia’s high dependency on the resource industries creates an economic vulnerability. Australia needs the capacity to create a more diversified and sustainable industrial base.

CSIRO has previously suggested that one way to help increase the absorptive capacity of industry would be through the development of ‘Australian Growth Partnerships’. An Australian Growth Partnerships’ competitive program would provide funds directly to SMEs so that they could engage in large scale collaborations with Australia’s leading providers of research services. The aim of the program would be to transfer technology to those SMEs most likely to succeed – to those that have already successfully developed and commercialised technology. Past success would have honed the necessary management skills and created business infrastructure and relationships able to expedite the execution of new technology development projects. SMEs benefiting from the program would repay the funds they had received. If participation did not result in successful commercial outcomes, no repayment would be necessary.[62]

The Australian Growth Partnerships proposal has aroused considerable interest. *Pathways to Innovation*, the June 2006 report of the House of Representatives Standing Committee on Science and Innovation, has recommended that

> … the Australian Government give priority consideration to the Commonwealth Scientific and Industrial Research Organisation’s proposal for an Australian Growth Partnerships program to engage small to medium enterprises in demand driven collaborations with publicly funded research agencies.[63]

Discussions of absorptive capacity tend to concentrate on manufacturing, where technological problems are often quite specific to individual firms. In other sectors the problems may be different. In agriculture and natural resource management, for example, the transfer of knowledge, learning and technology can depend to a high degree on extension services and consultants. The need is to provide the relevant information and to demonstrate its use, not to individual firms but to all the relevant enterprises or groups within a sector. However, there is a complication in that putting the research into practice might require some tailoring to local conditions, so that those responsible for transferring the research results need a significant level of technical expertise.

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[62] The model is similar to that of the Higher Education Contribution Scheme (HECS) and the rationale for adopting the model is the same in both cases.
[63] http://wopared.parl.net/house/committee/scin/pathways/report/fullreport.pdf

A lessened emphasis on the provision of extension services need not reduce the impact of research but might well mean that it takes longer for the science to achieve its full impact. More resources for extension services can help speed the uptake of new technologies and, by providing customer feedback, even help speed the pace of new developments.

Because it is a commonwealth statutory authority, CSIRO can play an especially important role in delivering impact from public good research. Such research often makes a difference by helping to inform the development of policy. In some cases this can be direct (eg advice on the sustainable yields of fisheries) in other cases (such as an understanding of probable changes in climate) it may provide the context within which a wide range of policy decisions is made. As a commonwealth statutory authority, CSIRO is able to work as an internal player within government. This allows CSIRO to play a direct role in providing advice to government to inform policy development.

One of the factors impeding the effectiveness of CSIRO in helping to inform policy development is that departmental officers do not always recognise the contribution that CSIRO can make and may not seek CSIRO participation early in the policy development process. Conversely, there is still some uncertainty within CSIRO about how the organisation can best use its scientific expertise to engage in policy issues. The organisation is working with departments and agencies to refine the way in which CSIRO can increase the effectiveness of its contributions to policy development. It is working to facilitate and increase engagement on both sides and examining how best to ensure the continuing dialogue that is necessary to maximise impact. However, helping to inform policy development does not necessarily mean that policy will reflect the best scientific advice. This is because many factors other than science play a role in reaching policy decisions and governments sometime shave their own political agenda that operates independently of technical advice.

Skills and entrepreneurship

A theme underlying any discussion of absorptive capacity (or of knowledge transfer more generally) is that it depends on people. In particular, it depends on people outside the research system who understand the possibilities that research can present and have experience of the context in which it is necessary to develop these possibilities. It depends on people with an entrepreneurial culture and skills – people who recognise opportunity and will take the risks necessary to convert opportunity to reality.

A strong university and education sector is necessary to develop the human capital on which all innovation depends. Skilled people with expert knowledge and an ability to think creatively are necessary right across the innovation system. We need people not just with scientific, technical and research skills but creative marketers, a world class financiers, expert managers, risk taking entrepreneurs, and so on.

Just as the individual elements of the research system interact in complex ways, so do the components of the education system. Universities and the elements of the vocational education system are especially important in supporting innovation and play complementary roles. In particular, the technical skills that people gain through the VET system can be very important in facilitating the incremental technical innovation that provides the small, continuous improvements in efficiency and productivity that can be so important in maintaining competitiveness.

One problem arising from Australia's relatively low investment in research by business is that this limits the opportunities that scientists have to gain research experience in an industrial or more general business context. University-trained scientists, even if they move to the business sector, may have little direct experience of how business manages its research and integrates this into technology and business development strategies set firmly in a market context. This is one reason why CSIRO over recent years has increased the number of PhD and post-doctoral positions that it offers. Not only do people coming into these positions add significantly to the organisation's intellectual and creative capabilities, they also receive an opportunity to experience research towards the applied/development ends of the research spectrum. This exposes them to an accountability framework similar to that applied by business.

The converse problem is that in Australia very few researchers or university scientists appear to have had experience working in business. This can make it more difficult to produce scientists and researchers with a broader understanding of how business works and the ways in which science can contribute to business development. It is not easy to see how to address this problem. It may in part reflect a risk averse attitude on the part of academics here compared to those in some other countries, where it can be more common for scientists to try setting up their own business and later return to research or academia. One cultural issue that might play a part here is the way that in some countries bankruptcy is seen as a learning experience – a normal part of the path to success – rather than as a failure.

Scientific and technological literacy

Another respect in which people can influence the uptake of publicly funded research outputs is through their attitude to science. The technological literacy of a population and its awareness of factors such as risk can create an environment within which both governments and industry can find it difficult to innovate. The preparedness of a community to accept the benefits of new technologies can vary significantly. In a democracy it is natural that government's respond to community concerns. With a well informed population this does not present any problems. However, when public attitudes lack a sound basis in the understanding of the science, its potential risks and how it is possible to mitigate these risks, it may become difficult to use potentially important technologies. CSIRO's education and communication activities help to keep the Australian community informed and CSIRO's reputation as a credible and independent source of advice plays a critical role in the effectiveness of these activities and their overall impact – but there is always room for more work in this area.

The importance of ongoing support and reform

Importance of science and innovation

Science and innovation are crucial for Australia's future. There is no area of Australian life that does not benefit from the contributions that they make; and in some areas they are driving progress. Security, energy, industrial competitiveness, environmental sustainability, climate change, health and wellbeing, all provide obvious examples. Australia needs a strong domestic research base not just to address these issues but also to access the research conducted overseas.

Australian research generates a wide range of impacts – tangible and intangible, direct and indirect, long term and short term. The benefits of science can be cultural, social, environmental and economic. They extend into global engagement and Australia's international reputation. Focussing on one type of benefit can greatly underestimate the return from investment in research; and none of the benefits is a foregone conclusion. Investment is necessary beyond the completion of the research to produce the impact and convert the science to an innovation.

Innovation encompasses a diversity of activities, many of which have no direct connection with science, but it is technical innovation, based on scientific research, which generates new opportunities and responds to large scale challenges. Non-technical innovation, like incremental technical innovation, helps us do better the things we are already doing.

Arguments for government support

There are very strong arguments for government support for science and innovation. In some cases these are because the government is the direct customer for the research;[64] in other cases the arguments relate to market failure, often because of the high risks of the research or the difficulty of appropriating all its benefits.

The market failure arguments for government support can mean that it is more difficult to measure the full impact of government-supported science than of research funded by the private sector. Nevertheless, in providing support for science and innovation the government has to ensure that it operates to maximise the return that it receives from its investment.

Allocation of government support

Governments have to make choices about how they will allocate their support between different parts of the innovation system. The various components of the research and innovation system play different roles and aim to produce different kinds of impact. The targets of government support and the mechanisms governments use to provide this support should depend on the particular impacts they are trying to achieve.

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[64] The government's national research priorities display the diversity of the areas in which the government is looking for serious contributions from science, but they do not provide a comprehensive listing of the way that research benefits Australia and the government is the direct customer for only some of the priorities.

Firms in the business sector aim to internalise the benefits from their research, which aims to increase profitability and business growth. In the higher education sector research contributes significantly to the development of human capital, as well as having more direct outputs and outcomes.   Research in the government sector plays a variety of roles depending in part on whether the research agency is itself the customer for its research or whether the research aims to satisfy the needs of a broader range of stakeholders.

The various players in the research system plan, manage and evaluate their research according to their own roles, responsibilities and culture.

Complexity of the innovation process

Achieving impact from science through innovation is not easy and can be a complex, iterative process. Innovation depends on many players outside the research system and on a broad range of policy settings. If the government is to maximise the return it receives from its investment in science and innovation, it has to ensure that all parts of the system are operating effectively. However, depending on the impacts the government is trying to achieve, this will mean investing in particular parts of the system.

Differences between the innovation systems of different countries reflect, among other things, their history, culture, governance arrangements, industry structures and geographical location. Australia's history, earlier dependence on the agricultural and resource industries, long history of protection and federal structure have meant that the government has a more important role to play in performing research than in some other countries.

Importance of CSIRO's role within the innovation system

Within this context CSIRO plays a particularly important role. This is in part because of its size, the diversity of the expertise that it contains, the breadth and depth of its linkages (both formal and informal) with other players in the innovation system and its appropriation funding. These allow CSIRO to develop and implement large scale, long-term research projects, managed for outcomes, beyond the capabilities of other players in the system. Moreover, because of its scale of activity and role in managing collections and facilities, CSIRO forms a significant part of Australia's scientific capability and capacity to respond. The research that CSIRO performs generates options and opportunities for government, the private sector and the general community.

The importance of CSIRO also stems from its ability to operate as a single enterprise, rather than as a collection of separate operating units. This enables CSIRO to adopt a strategic, portfolio approach to the planning and management of its research; it also allows CSIRO to pull together the truly multidisciplinary teams necessary to address the increasingly complex and complicated questions that government and other stakeholders need answered.

CSIRO differentiates itself from other parts of Australia's research system by planning and managing its research strategically, at the enterprise level, to ensure that the research is relevant for Australia and will have impact. The organisation emphasises the tangible outcomes that require, but go beyond, the excellence of its science. At the same time, CSIRO research is multi-objective and the organisation's intent is to maximise the benefits of its research across all areas – not just economic outcomes.

Over recent years CSIRO has demonstrated a high level of internal innovation, responding to changes in its operating environment and government expectations. One feature of this is that it has introduced organisation-wide processes to plan, manage and evaluate its research. Many of these processes rely on outside expertise and external interactions.

CSIRO does not monitor research projects in isolation from each other but as part of a portfolio of related projects aimed at achieving an explicit value proposition. While the organisation's research has to be excellent, it also has to have a clear path to application and achieve impact goals for continued support. This allows the rapid redeployment of resources from projects which will not meet their goals to projects that will have a greater impact. A major advantage of this approach is that it helps manage the downside risk faced by co-investors in the research and makes it more attractive for industry and other partners to work with CSIRO.

As well as facilitating and promoting early engagement with potential users of research outputs, CSIRO has also invested heavily in a wide variety of technology transfer activities to achieve impact. This has recognised the need to use a variety of approaches and to be creative in identifying mechanisms that can promote the application of research, whether working in a market pull or technology push environment. Building path to impact considerations into research planning, and early engagement with research users, have been central elements of this strategy; but CSIRO has also had a process of taking action to encourage the application of intellectual property it has already developed.

CSIRO has had a long tradition of using a variety of complementary methods to demonstrate that it is having impact and has used cost benefit analysis to demonstrate that the return on the government's investments exceed its cost. However, the organisation appreciates the problems that can exist with current approaches and that refinements are continually taking place in impact measurement. For this reason it has commissioned an independent study by ACIL Tasman. These consultants will help CSIRO conduct an impact assessment using an overarching real options framework. In addition to providing sound data on CSIRO's performance, this analysis also has the potential to refine CSIRO's decision making and resource allocation processes.

Addressing impediments

Many of the management and technology transfer processes that CSIRO has introduced (and is introducing) address potential impediments to science creating impact. Earlier parts of the submission have explained, for example, how CSIRO works with the business sector and uses methods such as co-investment to help firms manage the risks of investing in research, or how CSIRO's simplification of contracts is reducing the transaction costs of organisations working with the organisation.

While CSIRO strives to be effective within the existing system and works to overcome its constraints, there are some changes that would help improve CSIRO's performance. One would be to introduce an Australian Growth Partnerships type program or any other initiative that encourages existing, successful firms to take on the opportunities presented by new technological developments to create new markets. Actions that lead to more people in industry having a greater appreciation of science, technology and technical innovation would also help.

Improving the absorptive capacity of industry would help improve the effectiveness of all parts of the research system. One of the best ways of doing this is to facilitate the movement of people between the research system and the business sector generally. However, CSIRO believes that the approach it is taking with the flagships, involving early and continuous engagement at both a strategic and tactical level with potential users of research (whether government or business), has demonstrated considerable success. The factor limiting CSIRO's ability to move faster with this approach is the lack of funding, particularly the appropriation funding which provides the foundation for this approach.

The challenge for Australia

One of the challenges for Australia is to determine what level of government support for science and innovation is appropriate. There is no easy answer. Benchmarking can help demonstrate what other countries are doing but this is an area in which differences are important. What makes sense in one country need not be relevant in another country. This is not only because of the complex differences that exist between the innovation systems of different countries and the many local factors that can determine the effectiveness of government investments. It is also because government policy objectives and capabilities can be very different.

Despite the difficulties that exist, there are some clear pointers about direction, if not absolute levels for government investment in science. One comes from the high targets (3 per cent of GDP) for research expenditure set by the European Union as part of its Lisbon Agenda;[65] and increases in government research expenditure in countries such as the USA.[66]

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[65] European Commission Research, Towards 3% of GDP http://europa.eu.int/comm/research/era/3pct/index_en.html

[66] President Bush announced the American Competitiveness Initiative (ACI) during his State of the Union address during January 2006. President Bush stated that an aim of the ACI is to "…*encourage American innovation and strengthen our nation's ability to compete in the global economy*". Over a ten year period the ACI requires the US Government to commit US$50 billion to increase research and a further US$87 billion for R&D tax incentives. The US Congress has approved President Bush's 2007 Budget request for US$5.9 billion as an initial instalment on funding the ACI.

Another indicator comes from the rapid developments taking place within our region and the focus in countries such as India and China on improving their innovation systems, investing more in research and creating world class universities. This is already changing the world's economic centre of gravity. In the short term the economic growth of these countries has created demand and high prices for our mineral and other resources but this is unlikely to continue in the long term.

Australia has to develop its capacity to compete in a rapidly changing world: a world that relies more on the intellectual content of goods than on their material content; and in which new and innovative services linked to advances in technology account for an ever greater proportion of economic activity. It is also a world in which trade, the movement of capital and the movement of people is becoming easier and taking place faster.

Australia's survival in this world will depend on our ability to create new products, processes and services in niche areas that build on our capability. In other words, as other countries increase their capacity to innovate it becomes ever more important that we also strive to improve our performance, if our relative position is not to fall.

The way ahead

CSIRO's belief is that the kind of approach it has used to develop and implement the National Research Flagships demonstrates the way forward to address these challenges, a conclusion that receives strong support from the feedback CSIRO receives on this activity and the very high quality partners linking up to the program. This approach operates within and across Australia's national innovation system to build capability, create options for future action and generate significant outcomes that Australia cannot achieve in any other way.

Promoting this approach more widely would require each component of the national innovation system receiving public support (including funding bodies) to:

- clarify its role and purpose, to identify those characteristics that differentiate it from other parts of the research system and to concentrate on what it can do best;
- collaborate with other organisations when these have the complementary skills, characteristics or infrastructure necessary to do a job well;
- manage its research for impact, concentrating on achieving those impacts that flow from its agreed role;
- use transparent governance processes that deliver accountability to taxpayers while providing the data and information necessary to support internal research planning, management and evaluation processes; and
- focus on the quality of its underlying capability, given the purpose of that capability and the complementary assets available elsewhere within the Australian research and innovation systems.

Putting these types of processes in place across the broader innovation system and sustaining them through a diverse range of clearly differentiated funding and other support mechanisms, managed according to what they aim to achieve, would help reduce unnecessary duplication, increase accountability by increasing transparency, and improve the efficiency and effectiveness of the national innovation system. By providing a more explicit base for the active evaluation of the portfolio of public sector research, this would help generate the range of impacts the government is seeking to achieve through the support it provides.

The overall lesson is that it is necessary to use practical and appropriate planning, management and evaluation processes to achieve impact; that the nature of these processes will and should vary, depending on what impact you are aiming for; and that specialisation within a diverse innovation system can ensure that public support maximises the impact it has, even though different parts of they system are aiming at different impacts. All this requires management and funding processes that focus on quality and which maintain the quality of Australia's underlying capabilities as well as the excellence of the outcomes this capability creates.

ATTACHMENT 1

CSIRO's functions as stated in the *Science and Industry Research Act 1949*, as amended

9 Functions of the Organisation

(1) The functions of the Organisation are:

(a) to carry out scientific research for any of the following purposes:

(i) assisting Australian industry;

(ii) furthering the interests of the Australian community;

(iii) contributing to the achievement of Australian national objectives or the performance of the national and international responsibilities of the Commonwealth;

(iv) any other purpose determined by the Minister;

(b) to encourage or facilitate the application or utilization of the results of such research;

(ba) to encourage or facilitate the application or utilisation of the results of any other scientific research;

(bb) to carry out services, and make available facilities, in relation to science;

(c) to act as a means of liaison between Australia and other countries in matters connected with scientific research;

(d) to train, and to assist in the training of, research workers in the field of science and to co-operate with tertiary-education institutions in relation to education in that field;

(e) to establish and award fellowships and studentships for research, and to make grants in aid of research, for a purpose referred to in paragraph (a);

(f) to recognize associations of persons engaged in industry for the purpose of carrying out industrial scientific research and to co-operate with, and make grants to, such associations;

(h) to collect, interpret and disseminate information relating to scientific and technical matters; and

(j) to publish scientific and technical reports, periodicals and papers.

(2) The Organisation shall:

(a) treat the functions referred to in paragraphs (1)(a) and (b) as its primary functions; and

(b) treat the other functions referred to in subsection (1) as its secondary functions.

Arguments for government funding of research

Research is not an end in itself. When business funds research the knowledge it seeks will generally relate to the development of new or improved products, processes, materials or services. The benefit to the firms conducting or funding research comes from the increased competitiveness that results from applying the research findings, greater market share and increased profits. In other words, the benefits come from innovation, not research.[67]

Competing in a world of rapid change, it is axiomatic that firms need a process of continual innovation to maintain their position, let alone improve their performance. There is no doubt that research is a major driver of technical innovation, both directly and indirectly. Not only does research lead to new and improved products and processes, it develops capability and an openness to new ideas that facilitates other forms of innovation. The returns to a firm on its on investment in research can be considerable.

While it is clear why business might decide to invest in research, the arguments for government support are different. This is important because an assessment of the impacts of public support for science and innovation should reflect the rationale for providing the support. It is not appropriate to carry out a direct comparison between the business and government sectors.

All governments support science and innovation, especially by providing support for research and development. One reason for this is the belief that private agencies are unlikely to invest at a level that is in the national interest. This is because research will produce community benefits for which those funding the research cannot charge. Another reason relates to the risks involved in research. The possibility that funds may be spent with no return again means that firms invest less than might be best for the nation as a whole. Other reasons for private sector under-investment in Australia relate to the small size of many Australian enterprises. Small organisations lack the resources and expertise to conduct research on a sufficiently large scale to produce worthwhile results.

While under-investment in research and development is a major reason for government support, a further reason is that the allocation of research and development funds by the private sector, irrespective of its level, may not be socially optimal. In other words, there may be areas of research having the potential to benefit the wider community which the private sector is unlikely to fund. Most of these would relate to matters which are the responsibility of government.

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[67] The exception to this, and it is an important one, is where the purpose of the firm is to conduct research, either on a contract basis, or with a view to seeling the research outputs to another (often much larger) business. Some biotechnology companies operating in the pharmaceutical sector, for example, apply this kind of business model.

Government funding of basic research

Governments fund research undertaken to acquire new knowledge without any particular application or use in view. This can be seen as an intellectual and cultural activity that contributes to national status. The major customers for this research are other scientists and citation indexes provide a measure of its use. Basic research also makes an important contribution to the education and training of scientists who may then become involved in more directed research.

Basic research also plays a very important role in building up the knowledge base which will produce (often unexpected) economic and social benefits in the longer term. However while the results of basic research form the foundation of strategic and applied research, the time-frame for the expected benefits is such that private sector support is unlikely to provide funding support.

Government funding of its own research needs

Research and development are necessary for the effective performance of the government's own responsibilities and functions. Many of these do not relate directly to wealth creation, but to maintaining and improving the quality of life within Australia. There are various services (such as meteorology, defence, some areas of environmental management, health, and the testing, establishment and maintenance of standards and maintaining an emergency response capability), the benefits of which can flow to the whole community and which individual organisations cannot easily appropriate. The government provides these services and the effective application of research and development has the potential to improve their quality and reduce the cost of providing them.

Government funding of research that government will not use itself

As well as funding the research necessary to carry out its own functions and to ensure an appropriate level of pure basic research, the government also provides support for strategic and other research whose findings have the potential to benefit areas outside of government. This support recognises the importance of science and technology in developing new areas of economic activity and in improving the productivity and performance of existing industries, so making them more competitive. Government support recognises that market failures exist in this area and that the community as a whole will benefit from the development of a healthy, competitive industrial base which will improve the nation's economy.[68]

Difficulty of firms fully appropriating the benefits of their research

Strategic research conducted by industry may create knowledge that becomes a public good in the sense that firms cannot fully retain themselves the benefits that flow from it. Such benefits might include an increasingly skilled workforce, knowledge which is useful but not patentable, improvements to the environment, and so on.

[68] Technical discussions of the market failure tend to emphasise the spillover effects of research that result in particular from the non-rivalrous and non-excludability characteristics of information that the research produces.

As an example of the benefits that a firm cannot appropriate, consider a firm developing a new and more effective pesticide. This might increase its market share and profitability. However, the farmers using the new product might benefit from increased crop production, lower costs of application and having a better product at a lower price. The general community might benefit from lower levels of environmental damage and better quality, or cheaper, produce.

Because the benefits retained by individual firms are less than the total benefits that flow to the community, there will be a lower level of investment in research than a community perspective would justify. This is because each individual firm attempts to underspend on research and development, only undertaking those expenditures for which its own benefits will exceed its costs. In practice this means that each firm relies to the maximum extent possible on the research conducted by others and uses its own funds to consolidate or increase individual advantage. Government support for strategic research helps compensate for the under-investment which results from the difficulty of individual firms fully appropriating the benefits that arise from their own expenditure.

Climate change provides one obvious example of the need for research whose results are not readily appropriable but which is of significant social and economic value. Questions relating to the cause, nature and extent of possible climatic change and its consequences are of direct and immediate interest to almost every Australian enterprise. Accurate information on the likely impacts of change is necessary for planning and development activities in almost every sphere of activity, from tourism to the location of new power plants. However, because the results of such research are of great general significance, it is improbable that funding would come from any but a government source.[69]

Risk

The benefits of research and development are uncertain in two respects. There is a possibility that the technical outcome of the research may be disappointing; and even if the research has a successful technical outcome, this is no guarantee of commercial success. The perceived risks can make firms reluctant to make substantial investments in research, especially where other profitable and less risky investments are available. This reluctance to invest in research might be especially high among firms that have no research experience – and this includes the vast majority of Australian firms.

It is important not to underestimate either the level of risk involved in research for innovation or the extent to which this can influence or limit the investment decisions of firms. Greg A Stevens and James Burley[70] have analysed data from project literature, patent literature and experience, and venture capitalists to prepare success curves for industrial innovation. These curves provide data on the number of ideas it takes to come up with a successful innovation. The authors found that the different sources of information provided remarkably similar results.

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[69] However, firms that have a vested interest in the outcomes of such research my make significant investments in analysing it using their own systems – eg reinsurance companies focus on the impacts of climatic change

[70] Greg A Stevens and James Burley. *3,000 Raw Ideas = 1 Commercial Success*. Research.Technology Management 1997.

There are clearly differences between sectors. Drug companies, for example, typically require 6 000 to 8 000 starting ideas for every successful new commercial product. Across most industries, however, the authors found that it typically takes 3 000 raw ideas to produce one, substantially new, commercially successful, industrial product. From these 3 000 raw ideas, firms typically identify 300 on which the they are willing to take minimal action, such as performing a few simple experiments, or discussing the idea with management.

Of the 300 ideas that emerge from this first self-screening process, 125 will advance to the stage that they become a small project. These projects will have a high probability of producing a research output that will lead to a patent. Only nine of the 125 projects will develop into significant projects with large development efforts. Four of the large projects advance to the next stage of major development efforts. Less than half of the major development efforts (1.7 projects) reach the commercial launch stage.

On average only 59 per cent of commercial launches provides economic profit to the parent company – i.e. a success rate of 1 project out of 3000 ideas.

The Stevens and Burley data have most relevance to the research strategies of large firms because SMEs do not attempt to produce ‘substantially new’ industrial products. Nevertheless, these data help illustrate some of the problems SMEs face, given the risks involved in any one project. Moreover, when firms do consider research and assess the risks of possible projects, they factor in only the benefits that they can capture, not the social benefits that might result. Even if they decide to go ahead with the project, external suppliers of finance for research projects may charge an additional premium on the funds they supply for research investment. This is sometimes because they do not fully understand (and may therefore overestimate) the risk and because they seek an insurance against research failure.

Private sector attitudes to risk are different from community attitudes for two reasons. One is that firms ignore the potential social returns that might result from their investment in research. The other is that a firm may have less opportunity than society as a whole to share the risk or to reduce it by spreading it across a portfolio of projects. For these reasons, if the government does not provide support, the total level of research may be lower than society might wish, in terms of the potential benefits it might receive.[71]

One problem with the portfolio approach is that even successful innovations may produce a relatively small direct return (although it is possible that without this innovation the business might no longer exist). This result is consistent with the findings of Scherer and Harhoff, mentioned in the body of the submission and it is worth reflecting that these authors concluded that:

[71] One reason large firms account for such a high proportion of BERD world wide is because they can share the risks across a portfolio of diverse projects with the successful projects compensating for those that fail.

The outcome distributions [of returns on innovation] are sufficiently skewed that, even with large numbers of projects, it is not possible to diversify away substantial residual variability through portfolio strategies. [72]

This suggests that if a firm is to invest in research leading to radical innovation, it has to be sufficiently large to survive, even if all its innovation investments fail. While it may not be possible for most individual firms, it is possible for large, publicly funded research organisations to spread the risk through the diversification that becomes possible through managing a large portfolio of projects. Similarly, government support (through tax incentives, direct funding, or mechanisms such as non-recourse loans) can help share the consequences of failure over the entire community.[73]

Arguments that governments should fund research and development because of its high degree of risk have interesting consequences for performance measurement. Uncertainty pervades the whole area of research and development, but it is obvious that some projects are much more risky than are others. Research directed towards the development of incremental improvements to products and processes is much more certain, at least in terms of research outcome, than is research designed to initiate completely new technologies. Clearly, it is the really original and untried approach that has the potential to produce greatest long-term benefits, both for individual companies and the nation as a whole – but it is this approach that has the greatest risk.

If governments fund strategic research in order to share risk, this funding would be most effective in supporting projects of greatest risk (and of greatest potential benefit) when risk is defined in terms of research outcome rather than market acceptance. One difficulty with this approach is that the more strikingly original the research, and the greater the probability of research failure, the lesser the likelihood that directed types of funding mechanism will provide the necessary support if their performance measures do not recognise that failure is a necessary consequence of this funding strategy.

It is difficult to evaluate high risk research in terms of normal accountability mechanisms. This arises both from the long-term nature of such research and the fact that success, at least as measured in commercial terms, would, by definition, be low.

Need for critical mass

If research and development activities are to produce successful outcomes, it is necessary to harness the full range of expertise, skills and equipment needed to formulate the research problem, define the opportunities and solve the problem. Without the necessary critical mass, the research is unlikely to be successful. There are two aspects to this argument.

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[72] F.M. Scherer and Dietmar Harhoff, (2000). Technology policy for a world of skew-distributed outcomes. Research Policy 29: 559-566.

[73] CSIRO's approach of co-investment – sharing the costs of the research in return for a share of the benefits – is a direct way of addressing the market failure resulting from the perceived high risks of research.

The first of these is that the fragmented structure of much of Australian industry militates against sufficient research spending. This is because small enterprises with the potential to benefit from research lack the resources to conduct it themselves. In many cases they may even lack the personnel to identify the kinds of research from which they might benefit. From the community perspective this results in an under investment which public funding can help remedy. Providing funding support may not be the total answer to this problem because such firms may also lack the resources required to successfully exploit any research findings.

The second issue is that the facilities and equipment necessary to support complex interdisciplinary collaboration between scientists and engineers is expensive but an ever greater proportion of problems require an inter- and multi-disciplinary solution. Moreover, the equipment may require a level of use to justify its purchase which goes beyond the needs of even the most innovative small firm. In other words, it is not the size of the firms that is the problem but the scale of the research as measured by the diversity of skills, equipment and facilities needed to perform it. The scale of work required is beyond the resources of even medium sized firms, and the return on investment might be many years down the track.

Leadership

Strategic research aims to acquire knowledge that is useful, even if the potential applications are rather long term (in private sector terms). In most cases it makes sense to identify the potential users of the research and to engage them in the research process when initiating the research. In certain circumstances, however, the government may wish to take on a leadership role. This might result from the need to follow through opportunities identified from research funded for other reasons. A government might identify potential benefits as in the national interest but existing industry may not have the interest or capability to fund the necessary research. In such circumstances the government could agree to fund the research necessary to set up a commercial concern and to seek private sector investment at a later stage. In using this approach, however, it might be necessary to take steps to build the necessary industry capability at the same time as initiating the research.

Another reason for the government adopting a leadership role would be to fund strategic research (relating to the meeting of long term policy objectives) the outputs of which might have no immediate commercial significance. An example might be a decision to fund research on alternative energy sources at a time when no immediate difficulties are foreseen in the supply or use of traditional fuels.

Examples of work CSIRO performs for each of its roles

Science-based solutions for the community

R&D that tackles specific national interest issues facing Australian society and the world.

Description of role

- Provision of timely advice and information, research, and specific community solutions which inform and protect society and the environment.
- Knowledge intensive R&D strongly leveraging existing CSIRO technology, research and expertise.
- Technology transfer and knowledge diffusion typically occurs through publication, service provision and informing policy.

Value of the role

- Provides a rigorous scientific perspective to inform government policy
- Provides a substantial benefit to Australia by
    - Improving human health, safety and wellbeing
    - Reducing pollution and protecting the environment
    - Protecting society from various threats
- Builds deep connection to communities, government and industry
- Scientists excited by seeing their work benefit Australia
- Low technical risk to deliver significant national return

Examples

Control of Bitou bush

- Bitou bush is an ornamental plant, introduced accidentally from South Africa, and then planted for dune stabilisation: displacing native vegetation on the Eastern coastline, destroying its value as a wildlife habitat and restricting access to beaches.
- CSIRO and NSW Agriculture identified and researched seven biological control agents, including the Bitou bush seed fly
- Project cost of $2 million, with an estimated $45 million worth of benefits.
- Huge community benefit, solving a widespread environmental problem and improving the use the dunes

Formation and Control of nitrogen oxides (NOx)

- Use of zinc sulphide ore causes problems with the product from the smelter and increases pollution because of the kerogens within the ore.
- CSIRO created a dynamic chemical model of the smelting process so that remedial strategies can be developed.
- This will reduce the pollution problem and increase the saleability of the ore

Managing mice with a mouse

- 'Mouser' - a user-friendly CD giving farmers access to more than 20 years of scientific expertise.
- It contains a decision support key and a simulation model so the user can 'roadtest' different mouse control practices.

Delivering incremental innovation for existing industries

Research and development which incrementally improves efficiency and effectiveness of existing industries

Description of Role

- Science-based solutions that help provide lower/more competitive production costs and improved quality of goods/services for industry
- Knowledge intensive R&D which requires deep understanding of industry and domain expertise
- Often leverages existing CSIRO technology, research and expertise to deliver improvements to industry
- Traditionally focused on areas of high adoption and take-up

Value of the role

- Estimate of $4.2 billion spent on incremental R&D each year in Australia
- Delivers most of Australia's GDP growth and helps Australian industry compete on a global stage
- Delivers measurable outcomes in a relatively short time horizon
- Provides industry with insights, infrastructure and IP that it would not otherwise have
- CSIRO fills a gap caused by the lack of large corporate R&D and SME research
- Provides CSIRO critical connections and insight into industry
- Spans all sectors
- Creates new products, services and businesses, and improves the use of resources
- In some areas, small technical efficiency improvement results in huge economic benefit (e.g. 1% improvement in alumina recovery = $100m p.a.)

Examples

Gravity Thickener

- Gravity thickeners are crucial when processing minerals. They separate fine particles from fluids.
- A multidisciplinary team of chemists, engineers, fluid dynamicists conducted research.
- A key focus has been the application of a sophisticated computational model.
- Investment of $10m ($7m from minerals industry) yielded an estimated return of $545 million
- Incremental benefit to industry resulting in large absolute value due to the Australian industry size and scale

Air Cargo Scanner

- Developed by CSIRO for the Australian Customs Service.
- Based on dual neutron and gamma ray technology.
- Provides rapid, high resolution, non-intrusive and material specific imaging for enhanced detection of illicit substances in air cargo.
- Customs will fund the construction, trial and operation of an Air Cargo Scanner facility at Brisbane Airport, and screening up to 100% of commercial air freight.
- CSIRO will enhance the underlying technology and adapt to larger items (sea freight) and smaller items (aviation baggage)
- This research addresses a major national challenge and clearly contributes to the National Research Priority, Safeguarding Australia

Total Easy Care wool garments

- CSIRO and The Woolmark Company research tackling a host of easy care issues confronting pure wool and wool-blend products.
- CSIRO has developed technology that will maintain sharp creases and seams in garments after washing and tumble drying.
- Berkeley Apparel, a large Australian suit manufacturer, has used the results to produce a suit that maintains its shape and appearance after multiple washes. This product has generated a great deal of interest from domestic and overseas retailers

Solving major national challenges (Improve quality of life and / or reduce costs)

Research which provides solutions and innovations (in whole or in part) to key challenges facing Australian society

Description of Role

- Strongly outcome focussed, R&D intensive, mission directed strategic research. Often large scale, complex and multi-disciplinary
- Generally higher risk, long time horizon research, requires major investment
- National teamwork, collaboration and partnership are vital

Value of role

- Most significant contribution possible to Australia: helping to solve Australia’s most complex and important challenges
- Consistent with CSIRO’s historical value proposition to Australia: e.g. solve the “rabbit problem”, solve the “salinity problem”
- This is why many of CSIRO’s scientists come to work each day – very powerful emotional connection to “helping solve the world’s problems”
- Success in this domain ensures that CSIRO has relevance for Australia

Examples

Project Vesta

- Australia's susceptibility to bush fires presents a major national challenge to protect property, lives and timber assets.
- Studies of high-intensity experimental fires showed that previous prediction methods drastically underestimated the potential rate of spread in dry forests
- Research being used to reduce incidence of damaging forest fires and reduce health and safety risks to fire-fighters and the public
- Improved predictions are estimated to return over $400 million by reducing losses from fire events, preventing injury and death, and preventing timber losses.

Water for a Healthy Country Flagship

The Flagship was developed to co-ordinate, focus and enhance CSIRO's work on sustainable management of our water resources
The goals are:

- urban and rural water systems that cope with population growth, climate variability and change
- agricultural and ecological landscape systems that deliver increased profit and better environmental outcomes
- industrial and agricultural systems that profit from the innovative conversion of wastes to resources

The research is multidisciplinary, geographically dispersed, aimed at several specific issues in the first instance, and largely incremental, yet the overall effect is to address one of Australia's greatest national challenges

On-site generation of electricity reduces greenhouse gas emissions

- About two-thirds of the embedded energy in coal has been lost before the electricity reaches the home or office. Once there, another 50% is lost due to wasteful equipment and practices. All of this loss contributes to Australia's greenhouse gas emissions.
- Generation of electricity on-site using gas-powered microturbines eliminates the losses from distribution, and use of the waste heat for heating or cooling means that the raw fuel is more efficiently used.
- This research addresses a major national challenge through reducing greenhouse gas production.

Creating new or significantly transforming industries

R&D which contributes to or is responsible for the creation of new industries or significant transformation of existing industries

Description of Role

- Partnering to transform/create an industry through the use of technological innovation and risk sharing
- Strongly outcome focussed, R&D intensive, mission directed strategic research with scalable trans-disciplinary teams

- Generally higher risk, longer term projects
- Partners include large corporates, consortia and industry associations

Value of role

- Creates next generation industries – new products, services and businesses
- Creates jobs and wealth for Australia
- Increases competitiveness and sustainability of Australian industry through dramatic innovations
- Allows co-investment and risk sharing to encourage industry development
- Opportunity for scientists to work on the true cutting edge of industry challenges
- Demonstrates CSIRO's value and enhances CSIRO reputation

Examples

Robotic / Automated Mining

- This work is composed of a number of projects that produce physical devices to aid the productivity and safety of mining
- The benefits have been estimated at $4.5 billion, of which 94% is attributed to productivity improvement
- Individual projects would be considered incremental, but the overall effect of the collection of projects is transforming the coal mining industry.

Polymer Banknotes

- Development of a new polymer material, counterfeit-resistant and durable banknotes
- Done in collaboration with the Reserve Bank of Australia
- Annual savings of $20 million in the production of Australian banknotes and development of an export industry
- Role has been to transform the use and management of currency in Australia and overseas
- CSIRO is continuing to collaborate with Note Printing Australia on development of advanced-level security features. It is also expanding the reach of the polymer substrate technology into other secure documents

Conversion to fumigants for stored grain

- Work by the CSIRO allowed the Australian grain storage industry to convert from expensive spray-on residual pesticides to fumigation - less expensive and preferred by most export markets.
- An estimated benefit to the Australian grain industry averaging $80m pa, based on the cost savings of using fumigation versus other methods, and the benefits of shipping pest-free grain.
- This research has dramatically changed the way that business is done in the grain storage industry, and in the process, maintained Australian competitiveness in a highly competitive and subsidised world market.

Advancing frontiers of science

Advancing an internationally recognised frontier of science or technology; may provide a paradigm shift in understanding with broad implications

Description of Role

- Insight based research leading to a paradigm shift that has potential implications across multiple domains
- Potentially generates new science / technical platforms, capabilities and IP
- Often lead by eminent scientists with global connections
- World leading frontier research, cutting edge/hot topic research or high potential
  (personal passion) research
- Collaboration and connectivity to the global research community is key
- Often performed without a particular client / partner in mind

Value of role

- Key in maintaining Australia's and CSIRO's
  - position as a significant contributor to global science
  - ability to draw upon global advances in science
- Vital to sustain all other core roles
  - a key source of IP upon which all other activities can draw
  - enables connectivity with the international research community and trading of ideas
- High risk in terms of project success rate, but successful projects generally provide high returns
- Develops and maintains world class scientific talent in Australia

Examples

Gene Silencing

- Gene silencing can change the characteristics of plants and animals
- CSIRO is developing the technology for application in plants, animals, insects and aquaculture species. Applications include:
  - Therapeutic uses - silencing disease-causing genes
  - Development of new useful traits in plants (and potentially animals)
  - Development of pigs with organs suitable for transplant into humans.
  - Pest control - treatments that kill a specific species of insect without affecting other related species
- CSIRO has formed a dedicated cross-divisional commercialisation team to develop the substantial opportunity that exists across the different sectors globally
- Benefits to Australia will include:
  - acceleration of research for the benefit of industry
  - revenues form exploitation globally
  - novel human and animal therapeutics, pest control options, etc
- This has revolutionised molecular biology and opened up vast areas for further advancement

Pulsars

- An international collaboration of astronomers has discovered more than 700 pulsars using the Parkes radio telescope and the very first system of two pulsars orbiting each other
- The existence of gravitational radiation has been proved through this work.
- Completely new, high-precision tests of gravitational theories have been developed. Already, four different effects beyond those predicted by Newton's laws of gravity have been measured and are completely consistent with Einstein's general theory of relativity
- The discovery of this new binary system has been one of the "holy grails" of pulsar astronomy and will provide a wealth of astrophysical information for years to come
- This research is considered frontier science because it concerns understanding the universe itself and being able to test important scientific theories.

Molecular Electronics: electronics beyond silicon

- Molecular Electronics is a new emerging science area in the field of nanotechnology which may replace silicon device-technology in the next decade.
- The researchers in this field are confident of discovering unconventional behaviours in the electrical conduction of these single molecules that may be harnessed for the next generation of electronics
- This is categorised as frontier research because the research is at the cutting edge of a new science discipline and while potential areas of application are foreseen, the full extent of benefit is completely unknown

Satellite roles

Outreach and education

Promoting the importance of science and scientific research and its applications to students, parents, teachers and the Australian community

Description of role

- Increase awareness by school students, their families and teachers of the contribution of science, scientific research , and of CSIRO to our community
- Educate, engage and enthuse students, teachers and the wider community about science and its applications
- Encourage students to take up careers in science, engineering and technology

Value of role

- The popularity of science needs to be significantly increased to achieve a productive community – economically, environmentally and socially
- Effective science education programs can make a significant impact on students' and families' regard for science and the likelihood of pursuing higher studies in this area
- Appreciation of science is critical to informed debate on many issues in society including the acceptance of new technologies

- CSIRO Education strongly promotes awareness of, and regard for, CSIRO

Managing national facilities

The management, operation and enhancement of national facilities

Description of role

- The day to day activities associated with managing and enhancing the national facility
- Ensuring access both nationally and internationally to the facility
- R&D utilising these collections are covered in other core roles
- Identification of facility need, design, consensus building and creation of new facilities

Value of role

- A market failure generally exists where such facilities are required by society but they are not commercially viable
- Key resource to improve research of both CSIRO and external organisations (national and international)
- CSIRO can even play a role in attracting such facilities to Australia
- Such major facilities are one (and only one) benchmark for the judgment of whether a nation is world-class in its science
- Managing, operating, and enhancing such facilities can be a prestigious recognition of an organisation's world-class status
- In a facility where the R&D is tightly linked to operation and enhancement, CSIRO can add value to the facility beyond simple management
- Facilities are heterogeneous in nature – some facilities have greater national value than others

Example – Australian Animal Health Laboratory (AAHL)

- A maximum security laboratory that provides diagnostic and research services, created to underpin Australia's ability to cope with outbreaks of foreign livestock diseases
- The only laboratory in Australia at which exotic micro-organisms can be safely handled
- Has developed new diagnostic tests and vaccines and identified many new animal diseases in Australia
- The first facility in the world to be accredited by the world animal health organisation (OIE) as an international collaborative centre for new and emerging diseases

Scientific publishing services

To provide an effective and efficient scientific publishing operation servicing the needs of the broad Australian scientific community

Description of role

- CSIRO Publishing (CP) has a product range including: primary research journals, academic books and CDs, educational and general reference books, magazines and CDs, multimedia products and services

- Provides knowledge diffusion throughout the Australian academic sector
- CP is increasingly publishing papers from international authors

Value of role

- Aids in distribution and dissemination of scientific information
- Disseminates Australian science globally while running as a stand-alone profitable business
- CSIRO Publishing leverages CSIRO's strong brand and also reinforces CSIRO's brand and the global impact of its science
- The role of publishing the journals of the Australian Academy of Science is highly regarded by the Australian scientific community
- Many of CSIRO Publishing's journals have significant international reputations, e.g. Australian Journal of Agricultural Research. The quality of the publications has continued to increase over the years

Supporting postgraduate/postdoctoral development

Training that actively develops next generation of Australia's scientific/innovation community

Description of role

- Training that develops the next generation scientists includes work with undergraduates, DPhils and Post-Docs
- This role is distinct from the general training and capability building of CSIRO scientists which is present across, and central to, almost all of CSIRO's roles

Value of role

- Growth in quality and quantity of scientists, engineers and other professionals who work to maximise the impact of mission directed research programs
- Educating CSIRO's future collaborators
- Training within the CSIRO environment offers a differentiated experience
- Talent development for the nation and for CSIRO

Managing national collections

The creation, enhancement and maintenance of National Science Collections.

Description of role

- The identification and development of collections which are vital platforms to enable research, collections of unique Australian heritage or both.
- The day-to-day activities associated with maintaining and enhancing the collection coupled with operating / facilitating the collections use both internally and externally
- R&D utilising these collections are covered in other core roles

Value of role

- A market failure generally exists where such collections are required by society but they are not always commercially viable

- Key resource to improve research of both CSIRO and external organisations (national and international)
- Such major collections can be a high profile benchmark for the judgment of whether a nation is world-class in its science
- Managing, operating, and enhancing such collections are often an important part of preserving Australia's heritage
- Collections are heterogeneous in nature – some have greater national value than others

Examples

- National Insect Collection
- National Herbarium
- Australian Wood Collection
- National Wildlife Collection
- FRR Fungal Culture Collection
- National Fish Collection
- Air Archives
- Microalagae Collection
- Wood fungus Collection

Providing technical services

Provision of testing or technical services to industry and the community

Description of role

- CSIRO typically has a privileged position based upon a range of strategic assets including patents, developed tests and existing mature technologies. CSIRO is often well positioned to serve as an honest broker in providing technical services.
- Technology transfer typically occurs through provision of services and advice

Value of role

- Provides valuable service to government, corporate and SME sectors
- Leverages CSIRO brand reputation as independent 3rd party service provider
- These services often fill a market gap
- Enables CSIRO to develop market knowledge
- Priority areas may include testing and certification, manufacturing
- Provides financial return to CSIRO

Examples

- Termite testing
- Tile testing
- Food sensory testing
- Pharmaceutical component material contract manufacturing
- Greenhouse modelling
- NATA anemometer calibration
- Rock strength testing
- Hydraulic fracturing services

ATTACHMENT 4

Summary of some cost benefit analyses of CSIRO work

Measuring all the benefits flowing from CSIRO activities is an impossible task. Without a clear understanding of the 'counterfactual' — the world without CSIRO — it is impossible to assess the true impact that CSIRO has had and continues to have on the well being of Australians. However, given the large public investment in CSIRO it is important to assess the contribution made by CSIRO. This short paper, prepared in November 2003, draws on a series of reports prepared for CSIRO by the Centre for International Economics (CIE), Canberra. The references list the individual reports.

Review of Past Performance

To provide an initial perspective on CSIRO's performance, CIE compiled information on 65 projects that had been the subject of formal benefit-cost evaluation in the past (CIE 2001). On average, past performance in R&D is a good indicator of current performance and the returns on CSIRO past work have been high (Table 1).

Table 1: Summary Results of Past Benefit-Cost Evaluations

Output Group	Number of Past Projects Evaluated	Range of Benefit-Cost Ratio (BCR) Estimates	Number of Projects with a BCR over 5
Sustainable Minerals and Energy	7	3 to 39	4
IT, Manufacturing and Services	17	0.5 to 72	4 (no estimate for 8)
Agribusiness and Health	29	0.4 to 236	21
Environment and Natural Resources	12	0.3 to 29	6
Total	**65**	**0.3 to 236**	**35**

Analysis of Current Activity

CIE also analysed the pattern of benefits flowing from a number of projects, identified by CSIRO's Divisional Chiefs, that were being funded at the time of the analysis (CIE 2001). The report identifies an immense diversity of benefits already flowing, and anticipated to flow, from these projects. CIE's assessment found that:

- there is evidence of increasing rather than declining returns.
- value for money is implied, though it is not proven because the benefits are not formally quantified.
- information technology is core to much of CSIRO's work, both as an input and as an output.
- there is a strong emphasis on creating and using precision systems in a wide range of applications.
- improving processes and practice, by building on current knowledge, is emphasised as much as improving basic scientific understanding
- expanding areas are more multidisciplinary in nature
- different models for engaging with commercial partners are employed in different sectors.

Compared with the projects considered in past benefit–cost evaluations there was a much greater emphasis on new products and on the environment. In agriculture and minerals there was a strong trend to learning systems and precision systems, clearly supported by the recent developments in IT. And in all areas there was more multi-disciplinary approach and cross-divisional cooperation at a project level.

The nature and composition of benefits across each of CSIRO's then four output groups are described below and summarised in Table 2.

- **Minerals and Energy**: 17 projects. Benefits from these projects arise mainly by lowering the unit cost of production - utilising past lessons and precision approaches to do things better. New technology also featured, and - important in the highly competitive mining industry - almost half the projects were considered to reduce business risk. Of the 17 projects 9 had some positive impact on the environment, two of these on renewable energy. Three of the projects had a strong focus on occupational health and safety.
- **Manufacturing, Information and Services**: 38 projects. A number of these projects were developing very new technology - from nanotubes for the delivery of medicines to virtual reality workstations to train surgeons. There was a much greater focus on new products with 31 of the projects developing new products. Development of skills - in industry and the community rather than just within CSIRO - was also very important. Spin-off companies were more evident in manufacturing and provided one mechanism for transferring skills from CSIRO to industry. Products that contribute to improved human health were strongly represented in the sample of projects identified. While informing policy did not rate highly in this particular selection of projects there are a number of areas of ongoing work in the manufacturing area — on safety standards for food and air quality for example — that may actually be yielding very high, but hard to measure, public benefits.
- **Agribusiness**: 28 projects. Most of these projects reduced unit cost of production. Of 14 projects on the agricultural side around half focused on breeding higher yielding disease resistant varieties, and the other half on saving water, reducing chemical use and other costs through better management and new technology. A number of these projects also deliver environmental benefits, such as the project that reduces the methane production of cows as well as boosting growth rates. Seven of the projects more on the agribusiness side had new products as their main benefit, the majority with a healthy food focus that also impacts on human health. Reduction in business risk was an important impact for 8 of the projects. Environmental impacts featured in 8 of the projects.
- **Environment and Natural Resources**: 11 projects. The main focus here was on improving environmental outcomes either directly or through informing policy. There is considerable overlap between this sector and agribusiness and many of the projects also are expected to reduce production costs in the long run, most by addressing the environmental problems such as salinity. This category had the greatest proportion of projects that had improving skills as a significant outcome.

Table 2: Benefits Flowing from Selected Current Projects

Output Group	Sustainable Minerals and Energy	IT, Manufacturing and Services	Agribusiness and Health	Environment and Natural Resources
Number of projects	17	38	28	11
Share of projects with impacts on…	%	%	%	%
- Lower unit production costs	94	53	68	45
- Improved quality	24	50	18	0
- New products	29	82	61	5
- Reduced business risk	47	26	64	73
- Development of skills	18	45	39	73
- Improved human health	18	32	39	18
- Informed policy	6	3	4	27
- Reduced pollution	6	5	7	9
- Improved environmental health	53	13	32	82

Benefit Cost Evaluations

Evaluations of Projects for the 2001 Output Pricing Review

CIE (2001) reported the results of four new benefit-cost evaluations undertaken to provide information for the Output Pricing Review then underway. These projects were not randomly selected, but were selected as representative of then-current projects with proven outputs delivering a range of benefits across the public-private spectrum. The quantitative results of the benefit-cost assessments, including 95 per cent confidence intervals that reflect the uncertainty around the parameter values used in estimating the benefits, are summarised in Table 3.

Even at the lower end of the range of estimates these four projects are estimated to deliver substantial net benefits to Australia.

Table 3: Summary Results of Four New Benefit–Cost Evaluations [a]

	Project Cost	Project Benefit	Net Present Value	Benefit-Cost ratio	Internal Rate of Return	Sensitivity of Net Present Value	
						Lower bound	Upper bound
Project	$m	$m	$m		%	$m	$m
Robotic Mining	46.9	4520	4473	96	720	3319	6085
RoadCrack	4.8	440	435	91	45	261	900
aXcessaustralia Low Emission Vehicle	18.4	2399	2381	130	51	231	2792
Vesta Bush Fire Control	5.5	445	440	81	70	280	565

a 5 per cent discount rate, 2001 dollars.

- **Robotic mining** is a collection of 6 projects that aim to eventually completely automate coal mining, however the evaluation is based on the individual contributions to safety improvement and enhanced productivity.
- **RoadCrack** utilises innovations in vision technology to detect cracks in roads quickly and safely. This facilitates allocation of repair resources, providing cost savings for repair due to early detection as the cost of minor repairs is over 60 per cent cheaper.

- **The aXcessaustralia Low Emission Vehicle** is a hybrid powered car with potential health benefits and fuel cost savings estimated at $277 million. Though significant, this is small compared with the additional value added for the motor vehicle industry if, as anticipated, the vehicle is produced in Australia.
- **Project Vesta** has produced a National Fire Behaviour Prediction System and guidelines and training related to dry eucalypt fire behaviour and management. Anticipated benefits include a reduction in insured losses, lower uninsured timber losses, and fewer injuries and deaths.

"*Ex-ante*" Evaluation of Flagship Programs

During 2002 the CIE worked with CSIRO to conduct an *ex-ante* assessment of five proposed Flagship Programs (CIE 2002a). The evaluation did not focus just on the commercial benefits of the R&D programs. These form only a small share of the benefits in most of the evaluations so the numbers cannot be compared with gross domestic product (GDP) measures. The appropriate interpretation is in terms of values (reflected in terms of willingness to trade for dollars) people place on the outcomes. Most benefit-cost estimates measure economic surplus, which is usually many times greater than GDP. The estimates here go beyond this to explicitly reflect values placed on environmental and health outcomes as well as the economic benefits to producers and consumers. While the estimates do not reflect the benefits that accrue in terms of national pride, an enhanced sense of security or improved equity that can also be delivered by R&D, as these real outcomes are not able to be captured in terms of a dollar value, they do come closer to reflecting the returns to the public than the standard economic approach.

What emerges is the clear role that CSIRO already plays and will need to continue to build in facilitating the interface between the researchers and the end users. These end users are policy makers as often as industry players. What is also clear is the need for multidisciplinary and transdisciplinary research to deliver the objectives of the programs. The evaluations provide an estimate of the return on the R&D investment, including funding from industry and other partners in the R&D. The costs of implementation are also estimated and are taken into account in estimating the benefit flows. The benefit cost ratio reported in Table 4 is the return on a dollar of R&D invested, taking the implementation investments as given. The sensitivity analysis shows a large range of potential benefits are possible due to considerable uncertainty about the future operating environment and the degree to which the programs achieve their objectives. But even at the low end of the potential range the benefit estimates are very large. It should be noted that, since these assessments were conducted by the CIE, and partly as a result of insights gained through conducting them, there has been further refinement in the scope of the Flagship Programs.

Table 4: Summary of the *ex-ante* benefit-cost results for flagship programs [a]

Program	R&D cost CSIRO	R&D cost Total	Benefits	Net Present Value	Benefit-Cost Ratio	Internal rate of return	Sensitivity of Benefit-Cost Ratio	
	$b	$b	$b	$b		%	*Lower*	*Upper*
Energy transformed	0.15	0.62	49.0		79	57	26	na
Revitalising landscapes	0.03	0.07	16.5	16.4	227	20	121	258
Light metals	0.04	0.09	6.0	5.9	66	95	45	88
P-health initiative	0.21	0.21	88.7	88.5	418	89	174	540
Agrifood – delivering foods for health	0.21	0.21	21.4	21.3	105	169	74	135

a *All results reported are for a 5 per cent discount rate*

- **Energy Transformed.** This program explores three main avenues for reducing the energy content of production through more efficient production use and transmission of energy. The benefits accrue in terms of increased economic activity, health cost savings due to reduced urban pollution, and greenhouse gas savings. The gains to Australia come in terms of an earlier adoption of the kinds of technologies that are also being developed abroad and the greater suitability of the technologies to Australian industry and conditions.
- **Revitalising Landscapes.** This program aims to promote solutions to a number of environmental problems facing Australian agriculture, downstream water users and the health of the natural environment. The gross benefits accrue largely in terms of commercial agroforestry benefits, carbon credits and the value to farmers in improved yield resulting from soil remediation. There are also large non-market benefits from habitat and species protection and improved aesthetics.
- **Light Metals.** The objective of this research program is to develop a titanium industry in Australia as well as continue to support the budding magnesium industry and the well established aluminium industry. The estimates reflects the commercial returns to these light metals industries and by implication to the Australian economy.
- **Preventative Health.** The P-health initiative aims to develop diagnostic information and technology for early warning of seven key diseases in Australia. Changes in lifestyles can substantially reduce the development of conditions and early treatment can delay the development of serious conditions and prolong healthy life. The commercial returns from intellectual property (IP) and spin-off companies make up less than 1 per cent of the benefits expected from the P-health initiative. The indirect benefits of longer healthier lives is slightly greater than the benefits in terms of the reduction in direct condition related medical expenditures, which are borne by the public as well as private individuals. This comes with an increase in prevention expenditure, which when included give a benefit-cost ratio of 3.3.
- **Agrifood.** The Agrifood - delivering foods for health program focuses on developing new agrifood products for sale into the domestic and export market. The benefit estimates focus on the potential commercial benefits to the agrifood industry if the productivity improvements and price premiums thought to be available from the market can be achieved.

Six “*Ex-post*” Project Evaluations

To complement the *ex-ante* evaluations reported above, CIE were engaged to conduct an *ex-post* benefit cost analyses for six CSIRO projects (CIE 2003). These projects and their net economic benefits are summarised in Table 5.

The projects were selected on the basis of availability of key information, the availability of the key researchers or others with information on the project, and the stage of completion of the project. The projects chosen do not reflect a randomly selected sample of projects, so they may not be representative of CSIRO’s wider research portfolio.

Table 5: *Ex-post* Benefit Cost Analyses - Summary of Results

Project	**Description**	**Net Economic Benefit** [a]	**Benefit Cost Ratio**
		$m	
Bovigam	Research leading to the development of a test for tuberculosis (TB) in bovine animals. The research lead to the commercialisation of a Bovigam test kit by CSIRO and CSL.	107	5:1
Supercapacitors	Research into expanding the available surface area of carbon on which a charge can be stored. The research lead to the creation of a commercial entity being formed to commercialise the technology	436	9:1
Indian Ocean Climate Initiative	Research into the effects of the Indian and Southern Oceans on climate variability in south-west Western Australia leading to better information on water availability and prediction of weather events.	not quantified	not quantified
Mechanical pruning	Research into the mechanisation of wine grape crop pruning leading to lower human involvement and higher productivity in the wine industry.	247	50:1
Solospun™	Research into wool processing technology which led to Solospun™ being adopted in the Australian and New Zealand wool processing industry.	-4.2	0.03:1
EXCELGRAM™	Research leading to the production of a range of Optical Variable Devices, particularly the commercialisation of EXELGRAM™ technology.	-28.3	0.15:1

[a] The difference between the net present value of benefits and costs of research discounted at 5 per cent.

These *ex post* evaluations focus on the benefits that could reasonably be considered to have actually taken place as a result of the research. However, even *ex-post* analysis does require a minimal level of ‘speculation’ about the effects of research. In particular, the analysis must take a view about what would have happened in the absence of the research. Comparing what happened *with* the research, with this counterfactual ‘*without research’* scenario provides the basis for valuing the project. In some instances, the appropriate evaluation does require valuing future effects that have been set in train through the already completed effects of a project. Beyond this, however, *ex post* analysis allows the minimal speculation about research effects.

The projects are diverse and in many cases involved collaboration between CSIRO and other organisations. Four of the projects involved a commercialised product, which has subsequently been sold or licensed to third parties (Bovigam, Supercapacitors, Solospun™ and EXELGRAM™). These projects have led to an essentially private stream of benefits (many of which have accrued overseas), with minimal public good effects. Bovigam and Supercapacitors are estimated to have generated net benefits, while EXELGRAM™ and Solospun™ appear to have generated net costs.

One of the projects (the Indian Ocean Climate Initiative) involved almost entirely public good research. It was also the most difficult to evaluate, and in the end only indicative benefits could be provided. It was determined, however, that IOCI need only have a relatively small impact on its target areas to produce solid benefits.

Three Plant Industry Project Evaluations

CSIRO Plant Industry also commissioned the Centre for International Economics (CIE 2002b) to undertake *ex-post* benefit/cost analyses of three specific research programs:

- **Improving wheat productivity by use of break crops and nitrogen application.** This research led to the finding that break crops (such as oats, lupins, peas, linseed, Indian mustard and canola) inhibit formation of (some) soil-borne cereal diseases. In so doing, break crops ensure that the integrity of the root system of the subsequent wheat crop is not compromised, thereby allowing the wheat crop to uptake required nutrients and water. The research showed that the break crop benefit alone led to large yield increases (in the order of 20 per cent) for the following wheat crop. The absence of disease delivered a second benefit as the efficiency of added nitrogen fertiliser for dryland wheat was improved if wheat was grown following a break crop such as canola. This cost-benefit analysis considers only those benefits that follow from wheat yield increases brought about by the use of *canola as a break crop and the tactical use of nitrogen on subsequent wheat crops.*
- **GrazFeed decision support tool.** GrazFeed provides graziers with a useful tool to assist their farm management decisions. By enabling them to simulate the physical and financial consequences of a change in management practice it can aid more informed decision making, reducing business risk. The benefits of the GrazFeed tool stem from improved efficiency of animal supplementary feeding by users, visible in the form of savings in supplementary feeding expenditure.

The GrazFeed project has also led to other benefits that have not been quantified, including potential environmental benefits and skills development. In addition, the research undertaken to develop GrazFeed has been valuable in facilitating the creation of new products in the GRAZPLAN suite. Although the analysis does not evaluate these other tools it is clear that if they have similar adoption rates and yield similar, if not greater, efficiency in farm management, the potential net benefits to the grazing industry and the Australian economy could be substantial.

- **Cotton breeding and management support research programs**. CSIRO’s cotton breeding program developed varieties that have higher yields, increased disease resistance and reduced need for insecticides. In addition, computer programs such as SIRATAC and its successor, entomoLOGIC/ CottonLOGIC, have been developed by CSIRO to help cotton growers make management decisions to apply the minimum amount of insecticide at the time it is most needed.

These research programs are recognised as having been successful and were not chosen at random. The analyses confirmed that these research programs have been highly successful in achieving high returns to the Australian community. The total present value of the costs of these programs has been about $155 million. The total present value of project benefits, however, is estimated at over $6.8 billion, with most of the benefits and costs coming from the cotton research programs. In all cases, the benefit:cost ratios and internal rates of return are quite high and indicate substantial returns. Table 6 summarises the results.

Table 6: Summary of benefits and costs of three CSIRO Plant Industry programs [a]

Program	Present value of project costs	Present value of project benefits	Net present value	Benefit-Cost Ratio	Internal rate of return
	$m	$m	$m		%
Break crops research	47.9	892.0	845.0	19	55
GrazFeed	4.5	354.7	350.2	79	102
Cotton research	103.0	5 702.4	5 599.5	51	31

[a] Five percent discount rate; real 2002 dollars.

Conclusion: How much does Australia benefit from CSIRO's R&D?

Australian taxpayers support research and development activities by CSIRO to the tune of about $600 million a year. What do they get for their money? The answer is — a lot. But not all of the benefits are easy to quantify, and those that are easy to measure are more likely to be returns to private firms. The CIE's analyses highlight the wide variety of pathways through which benefits accrue from CSIRO research. The quantitative results lead to two clear conclusions. First, not all CSIRO research programs achieve measurable positive net benefits. If this were not the case one would have to ask if sufficiently challenging research problems were being addressed. Second, the value generated by the successful programs "pays for" the total investment in the Organisation many times over. CSIRO's research makes a major contribution to Australia's industry, society and environment.

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Excellent Science

Definitions of excellence

All research requires science that is rigorous, objective, capable of being repeated, and discriminates between alternative hypotheses, otherwise it cannot result in a successful outcome. However, away from investigator led science there are other factors that can be as important as the quality of the science. These factors can include delivery measures such as relevance to the problem at hand, the time necessary to deliver the research output, the market potential of the research output, the customer's capabilities to adopt different research solutions, and so on.

Different customers have different measures of excellence. Outside the academic research community, scientific excellence does not always mean only exciting or ground breaking science. Indeed, even within the research community there is an understanding that it is necessary within the overall system to perform important research that will not lead to major breakthroughs in understanding. Some approaches to excellence can be even broader. For example the Canadian government approach to excellence incorporates ethics; transparency and openness; and relevance; as well as quality.

Within the academic research community the number of times other scientists cite a research paper is a fair and reasonable reflection of the impact of the paper. This is because the primary purpose of investigator led research is to advance knowledge and improve our understanding of the world. The greater the change in our thinking that comes from a paper, the more successful the research that led to the paper. (Although in some cases a paper might receive many citations because it presents poor science and other papers are disputing its methods or conclusions.)

Researchers operating in mission directed or applied research areas (and this includes most of CSIRO's scientists) are aiming not just to advance knowledge and understanding, but to produce technological solutions that address identified problems or which respond to or create market opportunities. They do not always use publication methods that can result in high citation rates – even though their research may be both excellent and exciting. This is because customer requirements and the need to capture IP rights might make publication or rapid publication problematic. Moreover, the intention of much research is not necessarily to make quantum leaps in understanding. Rather, it is to develop a solution that the customer can use, taking into account what the customer needs. The main success factor is fitness for purpose. A solution that results in a great leap forwards in understanding may be too expensive or take to long to implement, or be outside the capabilities of the identified research users for other reasons. A mission directed strategic research agency may stop an otherwise exciting research program for the simple reason that it will not result in a workable market solution or would take too long to do so.

This is not to say that highly cited papers are unlikely to lead to triple bottom line outcomes. Some will but many will not, and certainly not directly. The gap between science and technology differs considerably in different areas of technology and science. In an area such as molecular genetics, scientific advances can quickly lead to commercial applications through a very direct route. In fields such as particle physics the gap is larger and not always as direct. It is important when studying innovation to recognise that the complexity of the system and differences between fields make extrapolating from one field to another at best uncertain and in many cases positively misleading. Many highly cited papers are unlikely to lead directly to identifiable triple bottom line outcomes but still make a major contribution to science. Other research projects that do not lead to highly cited papers can have large economic impact.

While different types of research performing organisations tend to specialise in different parts of the research spectrum and often operate in different fields, they make use of each other's output. There is a very high level of interdependency. In particular scientists operating at the mission directed strategic research part of the spectrum make extensive use of the investigator led research often performed in universities. This means, for example, that patents produced by business or government research agencies will often cite papers reporting on the basic research performed by universities. The connection between those doing the highly cited research and those making use of it is not always direct and is very often roundabout, depending on the particular technologies. The research environment producing the very exciting science is not always the best research environment within which to convert this to technology and the health of the overall system requires that we maintain both.

Mechanisms for ensuring fitness for purpose and excellence

The measures of research success will vary according to the purpose of the research and the need of the customer. Market led research requires different assessment criteria from those used for research exploring scientific opportunities (even though this might lead to serendipitous or unplanned commercial opportunities and a technology push). However, this still leaves the issue of how to ensure that resources go only to research that will produce the best value for money, defining value in terms of the intent of the research.

One common view is that contestable funding will lead to higher quality science and better outcomes than block funding. However, given the variety of purposes that research serves, it is not possible that a single competition with a single set of rules could provide the best outcome for all purposes. It is not competition in itself that produces the outcome but the competition in conjunction with a particular set of rules and the particular process used to apply those rules.

In the case of investigator led research, for example the intention might be to allocate funding to those projects that will have the most scientific impact. One common way of doing this is to assess the project applications using peer review processes.

Peer review is an effective way to evaluate the likely impact of a research proposal and is probably the best way to evaluate the quality of scientific work (although this is not to say that it does not have problems or that it is sufficient in itself). However, there is no need to restrict peer review to funding applications and it may be just as valuable, and even more effective, to have peer review of completed work – evaluating the outcome rather than assessing the potential of a project. Moreover, there is no reason at all why peer review should take place only in the context of contestable funding schemes. Indeed, around the world peer review is the usual method of evaluating the science and scientific outputs of block funded research agencies and peer review forms an essential part of CSIRO's science assessment process as discussed in the body of the submission.

Peer review:

- can take place at the level of projects, programs or institutions and in relation to applications for funding or with respect to completed research (i.e. performance)
- need not be just about scientific excellence but can (and should) cover other matters depending upon the purpose of the research.

The peer review of a program or an organisation (rather than of projects) helps ensure a sound, broad scientific base (platform) that provides customers the confidence they need that the organisation will address their problems in a scientifically sound manner. Moreover, a peer review at this level can and should involve more than scientific peers because the success of an organisation can require more than it having performed high quality science. For example, the *ex post* peer review processes employed by CSIRO's science assessment process examine not just the quality of the science, but also its relevance and the impacts it has had on the intended users of the research.

Research excellence does not flow from the use or design of a particular funding mechanism. Rather, it is the result of best practice research management and delivery, supported by the effective use of assessment and evaluation procedures that examine research performance as well as research potential. The evaluation criteria need to take into account the purpose of the research or organisation being assessed and should involve peers across all relevant areas of expertise, not just science.

Peer review should be only part of this process, which also requires regular performance reporting and the management of the research according to agreed performance measures.

There should be different performance metrics for different organisations, reflecting their particular mandates, although there should be some common measures as well. An effective evaluation system will include both input and output measures because at times of rapid change, or in the cases of long term projects, input measures may provide the only meaningful data available.

In judging the excellence of the science coming from a research performing organisation it is necessary to:

- understand the mission of the organisation, its goals and its strategies for achieving them;
- agree on the performance metrics the organisation will use and the extent to which relevant stakeholders must support with them;
- note how the organisation will use the agreed performance metrics in a continuous improvement process; and
- focus on the extent to which the organisation is delivering outcomes.

A science agency having the roles and responsibilities that CSIRO has must monitor and assess its science base and its scientific activities. However, these activities provide at best a very partial measure of its performance and impact because the excellence of its work has to result in innovation – the improved wellbeing of all Australians – not just exciting advances in knowledge.

Types of data used in the Science Investment Process

This attachment provides a generalised and illustrative account of the kinds of analysis and types of data that CSIRO uses in the course of its broad direction setting and science investment process. The analysis takes place with respect to each of the 'Industry Community Areas' (ICAs) identified in attachment 7.

Relevance

Value from R&D

The intent is to assess how much value the successful completion, adoption and use of R&D might create, taking into account the full range of potential economic, social and environmental benefits. The assessment does not confine itself to Australia ('value from R&D' is a global measure) or to CSIRO's traditional research activities. It compares what would happen with the successful completion, adoption and use of R&D with what would happen with no additional investment in research.

The process considers:

- How the benefits of successful R&D will be delivered or expressed; and the evidence that these benefits will be valued.
- Whether the necessary complementary technologies will be available.
    - If there is a significant mismatch between progress in one technology and in other technologies needed for a system to deliver value, then the benefits of technical progress will not be realised. For example, the laser would have had no impact on telecommunications without the development of optical fibre.
- The resistance of existing products or services to being displaced.

Indicators/ data include:

- Size of ICA (industry / market size, growth rate, employment, export etc)
- Addressable benefit to Australia
- Trends in the distribution of CSIRO science investment by ICA, examining both appropriation and non-appropriation funding
- Proportional distribution of CSIRO Expenditure among ICAs compared with all other Australian R&D Expenditure (public and private)
- Contribution of ICA to the economy, looking at both GDP and environmental risks
- Key environmental challenges relating to each ICA
- GDP trends – projected growth 2004-09 and OECD 13 yr change in contribution of ICA to GDP (1990-2002)
- Contribution of ICA to employment and changes in this measure over recent years
- World Trade trend
- Resource use by ICA (water and greenhouse gas emissions)
- Trends in greenhouse gas emissions

Whether CSIRO should be engaged and the role it should play

Even if research has the potential to make a major contribution to the development of the ICA, it is still necessary to consider whether this means there is a role for CSIRO

This assessment considers:

- CSIRO's mandate
  - Whether CSIRO has any specific responsibilities or restrictions relating to the ICA.
  - Whether there are general government policies or obligations bearing upon the level or kind of effort in CSIRO.
- Australia's National Research Priorities
- CSIRO's role compared with that of other members of the national innovation system
  - Whether the nature of the users or potential users of CSIRO's research results has any implications for the role of public sector R&D generally and CSIRO's role in particular.

This criterion may have particular implications for the balance between investing CSIRO appropriation funds and seeking external funds.

Possible data include:

- Australia's total R&D spend for each ICA
- Ratio of public/private expenditure for each ICA
- Ratio of R&D spend between CSIRO, other commonwealth agencies, higher education, state and territories
- CSIRO expenditure expressed according to the contribution each ICA makes to the economy (for example, CSIRO spend per $ value added and per employee
- CSIRO spend compared to each ICA's contribution to GDP
- Australian challenges and opportunities
- Trends in the balance of trade for each ICA

Relevance of R&D

This is to assess the relative importance of R&D in creating value for each ICA and whether science and technology are key to the development of the area. Among other issues this assessment considers the relevance of research and development to the problems and opportunities presented by the ICA:

- Whether science and technology are key components of possible solutions.
- Whether other factors are needed for successful innovation and what they are.

Possible indicators/ data include:

- An industry sector's own investment in R&D.
- Global business expenditure on research and development (BERD) – R&D intensity for major countries for each ICA
- Australian BERD trend fro each ICA
- Aust R&D intensity: Total $ spent on R&D per $m of value generated
- Aust R&D intensity: Industry $ spent on R&D (BERD) per $m of value generated

- OECD intensity in Business R&D Expenditures as a % of Value Added in Industry
- USA R&D Intensity: R&D Expenditures as a % of Industry sales
- Industry innovation focus: Industry action agendas
- Business innovation

Impact

Likelihood of adoption

This assesses the likelihood that research users will adopt successful research, develop it further if necessary, and put it to use. This requires an analysis of the state of “receptor” system for CSIRO’s research. Addressing this issue makes it necessary to consider:

- The willingness of partners / receivers (firms, resource agencies or individuals) to adopt and use R&D results.
- The ability of the likely partners / receivers to convert successful R&D into commercial or other value.
    - The identification of what will be necessary to realise the benefits from successful R&D. (Examples are capital investment; distribution networks; marketing skills; and, changes in an enterprise’s processes.)
- The identification of what factors would drive adoption of the research results.
    - Whether these driving forces are short-term or long-term?
    - Whether there are there factors, including community acceptance, likely to promote or impede uptake.

Possible data include:

- The proportion of external revenue to total expenditure by CSIRO for each ICA
- European Industry Innovation: New products (last two years) % of total sales

R&D productivity / potential

The intent is to assess how much technical progress would result from an investment of R&D resources. The purpose is to identify: those areas of science and technology which are most productive in enabling new applications or advances in applications; the number of highly productive areas for an ICA; and the breadth and size of their impact across the ICA.

When making the assessment, R&D productivity/ potential is evaluated as a global measure which is independent of any particular research group or organisation. This assessment takes into account:

- The scope for technical progress (or technically-based improvement in performance).
    - The larger the scope the higher the R&D productivity/ potential for the area.
- The likely cost of achieving this progress.
    - The higher the cost, the lower the R&D productivity/ potential for the area.
    - Time is often used as a surrogate for cost and it is important to consider whether technical progress is likely to be quick or slow.

- Technical progress must be measured in terms of parameters that are important for use of R&D in the ICA.
- The assessment considers the uniformity of technical progress, as well as the rate of technical progress in core areas of science and technology. This is important as if there is a significant mismatch between progress in one area and in those complementary areas needed to deliver value to end-users then the overall rate of technical progress will be viewed by the users of research results as relatively low.

Indicators/ data include:

- Global science and technology "hot spots"
- CSIRO research competitiveness (now and future networks)
- CSIRO's ability to make scientific or technical progress in a timely and competitive way.
  - Include CSIRO's research collaborators when making an assessment.

CSIRO research competitiveness

The intent here is to assess CSIRO's ability to make scientific or technical progress in a timely and competitive way. In conducting this assessment, CSIRO takes into account its existing and potential research collaborators. Factors taken into account include:

- The skills and experience needed and how CSIRO's base of skills and experience compare with similar efforts elsewhere.
- CSIRO's track record.
- Whether CSIRO can assemble internationally or nationally competitive research teams.
- Whether the necessary research infrastructure (equipment, buildings, or other facilities) is or can be put in place.

Measures of CSIRO's research competitiveness include

- CSIRO citations per paper compared to selected Australian institutions
- Ranking of CSIRO research in areas in which are ranked in the Global Top 1%
- CSIRO Divisional "Quality" as measured by customer value surveys
- CSIRO Divisional Intellectual property positions

ATTACHMENT 7

The Industry Community Areas used for the Science Investment Process analysis

Plant and forestry agriculture

Animal agriculture

Rural based manufacture

Energy

Minerals and metals

Chemicals and materials

Equipment and instruments

ICT

Infrastructure

Commercial and community

Health

Environmental frameworks

Atmosphere, climate, oceans

Land and water

Telescope

Other categories

- Flagships
- Overarching R&D
- Security

ATACHMENT 8

Some Achievements of the National Research Flagships

Across Australia there are now more than 250 industry partners and research collaborators involved in the Flagship program. In 2004/05 alone there were:

- 30 patents lodged
- 95 formal agreements signed with industry partners
- 9 major contracts signed (each over $500 000)
- $16 million received in partner contributions
- more than 200 scientific reports and publications produced

A small sample of key achievements from each Flagship include:

Energy Transformed

Successful Sequestration of CO_2 in Coal Beds

An international research project has for the first time successfully stored carbon dioxide in European coal beds. The RECOPOL project (Reduction of CO_2 emission by means of CO_2 storage in coal seams in the Silesian Coal Basin of Poland) was a research and field demonstration involving the Energy Transformed Flagship and numerous research institutes, universities and industrial partners.

The storage of CO_2 in unusable coal beds demonstrated in the project is an exciting achievement. Australia has one of the highest greenhouse gas emissions per capita in the developed world, due to the structure of its energy industry. It is a national imperative to reduce these emissions, particularly from fossil fuel power generation. Successful sequestering of CO_2 is vital.

Food Futures

Healthy New Future for Omega-3 Grains

The Food Futures Flagship is the first research program to develop plants that produce the healthy omega-3 oil component docosa-hexaenoic acid (DHA) in their seeds.

Normally only available from fish sources, DHA is vital for human health. Showing that plants can produce this component via their seeds is an important first step towards improving human nutrition, reducing pressure on declining fish resources and providing Australian grain growers with a new high-value crop.

Prototype plants were developed by scientists to demonstrate that land plants can indeed make their own DHA and other important long-chain omega-3 fatty acids.

Light Metals

Making Titanium More Affordable

Researchers have demonstrated a new low-cost approach to producing titanium. Titanium is prized in industries, such as aerospace and biomedicine for being strong, light corrosion-resistant and biocompatible.

The Flagship has achieved proof-of-concept of its TiRO™ process, based on 'fluidised bed' technology involving continuous high-temperature conversion of titanium tetrachloride.

The TiRO process produces titanium powder faster and at a lower cost than traditional methods. A pilot plant has been producing titanium powder at the rate of 200 grams per hour.

The team is currently seeking a partner to support the next stage of scale-up, which could lead to the construction of a commercial smelter in Australia.

Preventative Health Flagship

Microencapsulation Technology

The Flagship has developed technology to encapsulate functional food ingredients within a microcapsule. Early indications suggest this protects against digestion in the upper intestine and allows their targeted delivery to the colon. This may pave the way for the development of foods that can deliver a range of bioactives to selected sites within the digestive tract, with the aim of delivering protective agents against colorectal cancer and other intestinal disorders.

Micoencapsulation has been identified as a key patent-protected technology with potential for the delivery of dietary bioactives and incorporation into new marketable functional foods.

Water for a Healthy Country

Water for Development: Perth and South-West Western Australia

The south-west of WA has been severely affected by climate-change. Rainfall is 10-15% lower than it was 30 years ago and inflow into local dams has halved in the same period. Demand for water is doubling approximately every 15 years, due to population increases and lifestyle needs.

The Flagship, in partnership with the Office of Water Strategy, Department of Premier and Cabinet, WA Government, WA Department of Environment and Water Corporation, has completed a 'whole of system' analysis of existing and potential water resources for south-west WA.

The findings provided smart, low-cost investment solutions for the region and are now supporting the State's investment in the Integrated Water Supply Scheme – ensuring Perth and the south-west's development and ability to cater for an increasing population and lifestyle demands.

Wealth from Oceans Flagship

Ocean Forecasts Now a Reality

For the first time, the Royal Australian navy is using near real-time ocean temperature, ocean currents and salinity information to support its maritime operations.

These web-based products are the first deliverables of the $15m BLUElink collaborative program between the Wealth from Oceans Flagship, Australian Bureau of Meteorology and Navy.

The program integrates information from satellite and ocean observing programs into a coherent picture of the present ocean conditions. The system is designed to predict ocean currents, temperature and salinity fields up to 10 days in advance.

The present products are producing reliable results and highlight a major achievement in the audacious plan to deliver an operational ocean prediction model to Australia by June 2007.

Examples of CSIRO's achievements from the 2004-05 annual report

Contributions to Innovative and Competitive Industries

Lower (more competitive) unit production costs

- Improved motors for domestic appliances (Electrolux)
- Optimum gas control strategies for underground coal mines (Coal industry)
- New software to manage operational risk (Major banks)
- Resistant chickpeas reduce the use of insecticides (GRDC)

Improved quality goods and services

- Improved quality and efficiency in cheesemaking (Dairy RDC / industry partners)
- Machine washable wool blend suits (Chinese textile manufacturer)
- Enhancing satellite communications (DSTO / BAE Systems)
- Improving environmental monitoring (BHP Billiton iron Ore)

New products, services or businesses

- The world's most accurate 'double corner cube' - helping NASA in the search for life beyond our solar system
- New contact lens for healthier eyes – O2OPTIX™ (Vision CRC)
- Tasty new table grape variety (Horticulture Aust, State Agric Depts)
- Successful semiconductor spinoff – EpiTactix

Contributions to A Technologically Advanced Society

Development of skills (enhanced human capital)

- Indigenous capacity building for exotic ant management (Indigenous organisations and communities)
- Summer students (Australian Pastoral Research trust)
- Integrated rangeland monitoring for the pastoral industry (MLA / State Depts)
- Centre for Low Emission Technology (Qld Govt / Industry / UQ)

Informing policy (cost-effective public programs or institutions)

- Addressing the barriers to distributed energy deployment (CenDEP)
- Sustainable urban water management in the ACT (Environment ACT)
- Groundwater management (NHT / FWPRDC)
- Balancing Act – a triple bottom line analysis (Univ Sydney / DEH)

Reduced risk (economic, social or environmental)

- Safer aeroplane panels (Boeing)
- Assessing coal performance for high pressure gasification processes (Coal CRC)

- Climate assessments for Melbourne's water resources (Melb. Water)
- New understanding of fungal infection in vines (CRC / Wine RDC)

Contributions to Healthy Environment and Lifestyles

Improved human health, safety and wellbeing

- Rodent control in Vietnam (ACIAR)
- Improving health with bioactive ingredients (ANZFA)
- CSIRO's Total Wellbeing Diet
- Identifying mental illness earlier (Westmead Hospital)
- New technology for longwall coal mining automation (ACARP)

Reduced pollution

- Stormwater project addresses water crisis (City of Geelong)
- New method to find mine derived sediment deposits (PNG gold mine / Univ Calif)
- Studying emissions from forest fires (National Research Centre for Environmental Toxicology / WA Dept CLM / Univ Melbourne)
- New cotton varieties released (Cotton Seed Distributors Ltd)

Improved environmental health

- Reducing saline groundwater (SA agencies / Aust Water Envts / Geoscience Aust)
- Monitoring water quality in Douglas Shire (Shire Council / Aust Govt)
- National carbon accounting toolbox for the land sector (AGO / ANU)
- Rock lobster fishery assessment

ATTACHMENT 10

Proposed approach to evaluating the impact of CSIRO

Introduction

The CSIRO is proposing a framework to assess the impact of its activities that seeks to address the following overarching question:

> *Would an informed community have preferred (or placed a higher value on) the set outcomes and options that were created with CSIRO R&D investment over the set of outcomes and options that would have been realised without CSIRO R&D investment?*

The approach is designed to work towards valuing CSIRO's contribution to Australia's well being in its broadest sense i.e. economic, social and environmental well being.

The proposed framework does not rely on a single methodology or approach

While we are proposing to use a real options framework to integrate different aspects of impact assessment, the framework does not rely on a single methodology. The framework essentially links a number of valuation approaches, and allows them to be used to contribute to a coherent assessment of overall value, grounded in contemporary economic theory. The overarching function of the options approach is to allow sound and consistent treatment of values already delivered and of value still in prospect, even in respect of completed R&D. In many cases, R&D that is lapsing can continue to offer both a flow of tangible benefits and an on-going stream of option values, relevant to commercial and wider social and environmental uses, and as an input to further R&D programs.

The proposed approach will use a package of complementary methodologies and tools (cost benefit analysis, real options - as a valuation tool, indicators, shadow pricing and threshold analysis) within an integrated real options valuation framework. The approach explicitly recognises the strengths of each individual method while accounting for their implicit weaknesses. We have only arrived at this position following completion of the Phase 1 work of ACIL Tasman, which was focused on critiquing the strengths and weaknesses of a range of assessment methodologies which clearly showed up weaknesses in most approaches not the least of which being not taking account of the counter-factual.

Value created will be estimated conservatively

The aim of the framework is to *conservatively* assess value from the bottom up. The method proposes to build up to both a lower bound estimate of 'quantifiable' value delivered and a characterisation of any remaining components of value that might be relevant to the overall assessment – all in respect of CSIRO activity under the current TFA agreement. The method aims to report on activity which has:

- already delivered (or is close to delivering) tangible economic, social and/or environmental benefits;
- highly prospective outcomes which are still in the discovery/innovation or development/innovation stage; and
- created value through building capability such as knowledge, skills or insurance (such as bio-security and safety).

Options value arising from terminated research will also be considered explicitly. This is a critical issue for us as we have implemented a performance framework over the past four years that underpins an active approach to managing our research portfolio that has seen us "fast fail" research not likely to achieves planned impact and more routinely redeploy resources and capability to what have been assessed as prospectively higher impact areas.   Benefits as conventionally measured using CBA techniques do not in all cases identify net benefits from terminated research that can include:

- Spill-overs within CSIRO (better future decision making, skills enhancement, etc.); and
- Knowledge to private sector implies potential cost savings (avoiding unnecessary R&D).

Again it is worth stating that the aim of the proposed framework is to use conservative assumptions to build to a lower bound estimate of CSIRO's value to the Australia. It is recognised that additivity can be an issue. However, an over arching real options framework can address this issue by ensuring that:

- the projects selected have a strong public good element, or market failure underpinning;
- the full costs of projects are recognised;
- they are drawn widely from the breadth of CSIRO work; and
- they are assessed within a whole of CSIRO 'portfolio' context, and with careful consideration and justification for the counterfactual – guarding against double counting, but also allowing exploration of any benefits from 'cross-fertilisation'..

The framework when implemented will utilise cost benefit analysis, real options and indicator methodologies to value impact

In a process sense the proposed approach will involve:

1. Reviewing, and if necessary updating, a wide range of past cost benefit analyses (CBAs) associated with R&D funded under the current triennium funding agreement in order to identify:
   - whether, with the benefit of hindsight, benefits and/or costs had been over- or under-valued;
   - the relative significance of wider value or costs which have been missed;
   - the likelihood that the outcomes will be realized and the decision points towards realization: and
   - if the aggregated net benefit of these reviewed and updated CBAs exceeds the value of the total CSIRO triennium funding;
2. Undertaking new *ex post* CBA's of tangible projects with a mix of social, economic and environment benefits which are in the deployment (adoption/delivery) stage of R&D to add to the benefit identified in 1 above.
3. Undertaking real options analysis of research in Divisions, Flagships or other collaborative projects (to be selected after discussions with internal and external reference groups) to value:
   - the options value of projects/areas of CSIRO work which show great promise but which would be extinguished or put on hold in the absence of on-going Triennium funding; and/or
   - illustrating the value of community driven outcomes such as solving major national challenges which can be difficult or impossible to value using traditional CBA approaches; and/or
   - science based solutions for the Community where uncertainties are high and impacts are indirect and often intangible and are difficult to fully value using traditional CBA approaches.
4. Reporting a suite of indicators to provide supporting material to illustrate the scale and importance of the science capability and R&D outcomes.

The valuation methodology will use shadow pricing and threshold analysis tools

It should be noted that shadow pricing (qualitative and/or quantitative) will be an important tool for working with non-market outcomes in respect of both the assessment of past and the undertaking of new *ex-post* analyses. Shadow pricing and the associated threshold analysis allow for the identification of the set of 'cost effective parameter assumptions' for independent assessment – including by political processes – but is capable of injecting into those processes much better information on relevant community values. For example,

- The analysis might indicate that an R&D investment would only appear cost justified if, in addition to tangible benefits already quantified, its package of outcomes in the form of approaches to better environmental management could be assessed as having value in excess of, say, $20m. It is often much easier to judge if the value would exceed such a threshold than it is to produce a credible point estimate;
- The basis for using such threshold information could be strongly complemented by a critical discussion of the indications of willingness to pay

for analogous outcomes available from the literature and possibly via a consideration of the shadow value attached by the Government to analogous environmental outcomes based on existing environmental policy settings;

– These approaches can provide a backdrop for a value judgment to be made, which can be set explicitly in an adaptive options context and may underpin a reasonably uncontroversial assessment of a lower bound of community willingness to pay for the package of outcomes.

The counterfactual will be assessed and identified

Again, it is recognised that the counter-factual is crucial to the analysis and determining the otherwise case is can be one of the hardest parts of any impact analyses process. In keeping with our objective it will be necessary to assess what outcomes can be truly attributed to the CSIRO's activity and what is different as a result of that activity. The counter-factual can be in part identified by devil's advocacy, an approach entirely consistent with the overall preference for conservative assessment of benefits and through independent third party input as to the criticality of CSIRO R&D contribution to total impact.