

REPORT TO
CSIRO

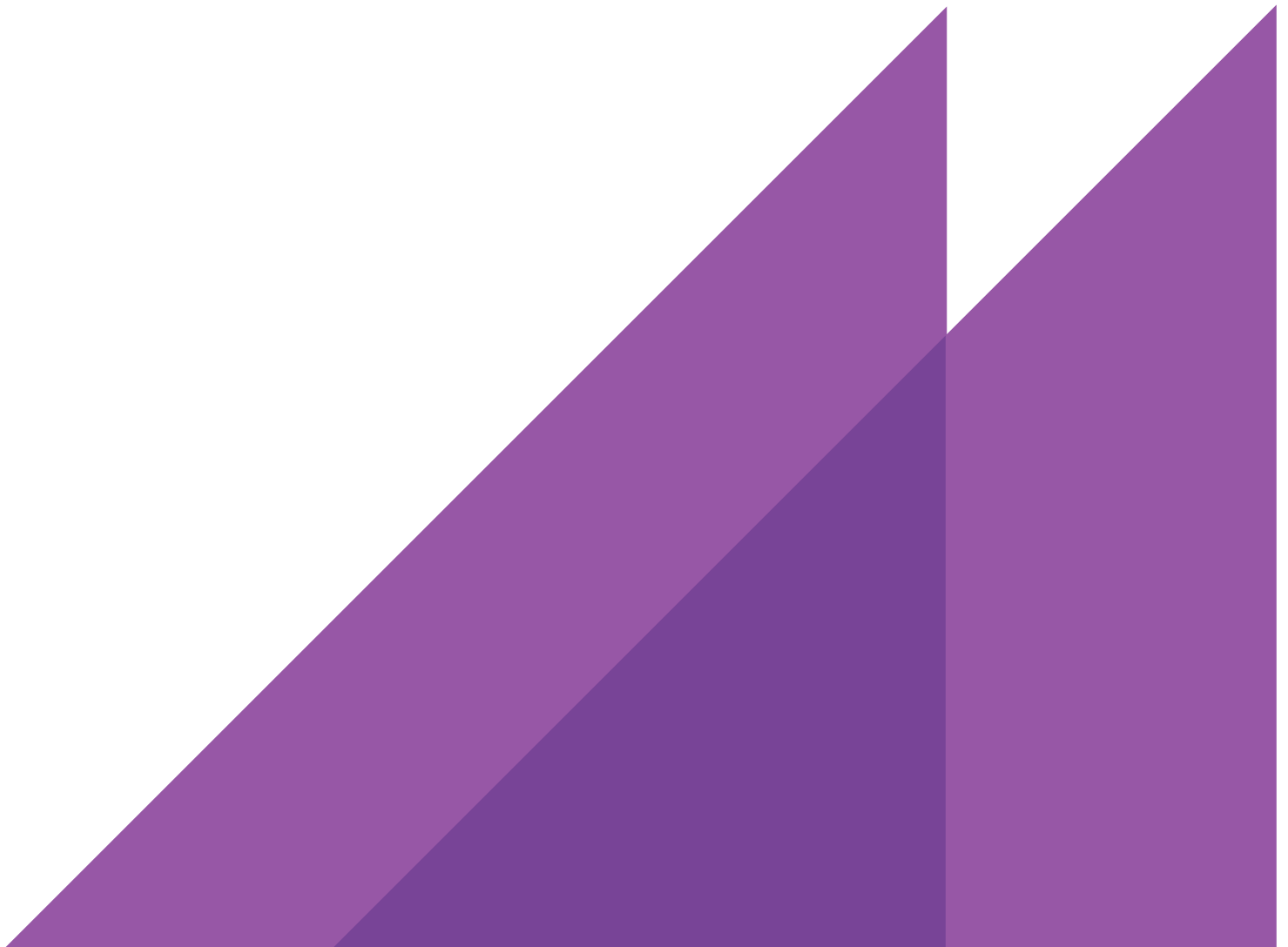
11 AUGUST 2017

THE VALUE OF CSIRO



AN ESTIMATE OF THE
IMPACT AND VALUE OF
CSIRO'S PORTFOLIO OF
ACTIVITIES

2017 UPDATE





ACIL ALLEN CONSULTING PTY LTD
ABN 68 102 652 148

LEVEL FIFTEEN
127 CREEK STREET
BRISBANE QLD 4000
AUSTRALIA
T+61 7 3009 8700
F+61 7 3009 8799

LEVEL ONE
15 LONDON CIRCUIT
CANBERRA ACT 2600
AUSTRALIA
T+61 2 6103 8200
F+61 2 6103 8233

LEVEL NINE
60 COLLINS STREET
MELBOURNE VIC 3000
AUSTRALIA
T+61 3 8650 6000
F+61 3 9654 6363

LEVEL ONE
50 PITT STREET
SYDNEY NSW 2000
AUSTRALIA
T+61 2 8272 5100
F+61 2 9247 2455

LEVEL TWELVE, BGC CENTRE
28 THE ESPLANADE
PERTH WA 6000
AUSTRALIA
T+61 8 9449 9600
F+61 8 9322 3955

161 WAKEFIELD STREET
ADELAIDE SA 5000
AUSTRALIA
T +61 8 8122 4965
ACILALLEN.COM.AU

SUGGESTED CITATION FOR THIS REPORT

THE VALUE OF CSIRO – 2017 UPDATE, ACIL ALLEN, 2017

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EXECUTIVE SUMMARY (THE ESTIMATED VALUE OF CSIRO)

CSIRO commissioned ACIL Allen Consulting (ACIL Allen) to update its 2014 estimate of the impact and value delivered to the economy and the innovation system by the public investment in CSIRO. Our key findings are summarised in **Box ES 1**.

BOX ES 1 WHAT IS THE VALUE OF CSIRO?



ACIL Allen's estimate of the impact and value of CSIRO finds that:

- The estimated present value of benefits across the 28 case studies where benefits data was available is approximately \$3.2 billion per year (2016/17 dollars, based on a 7 per cent real discount rate).
 - This is almost three times the total annual funding provided to CSIRO and more than four times the funding provided by the Australian Government.
- The case studies consider a small subset of the total research by CSIRO. ACIL Allen believes that it is reasonable to assume that the annual value delivered by all other CSIRO research would at least match that delivered by the case studies. In that case, total annual benefits from CSIRO's research would exceed \$6 billion.
This suggests that the full CSIRO research portfolio is providing an estimated return of over 5:1.
- The review of the assumptions for three past case studies provides confidence that the approach taken to estimate the impact and value of the case studies provides a robust and defensible estimate of the lower bound for the value of CSIRO's research.
- The qualitative discussion of the six other ways in which CSIRO could add value provides further confidence that the actual value delivered by CSIRO is likely to be considerably higher than the estimate based on the case studies alone.

In addition, CSIRO's structure and operational approach helps to create a culture and atmosphere of trust that encourages the emergence of ideas and collaborative partnerships which in turn enhances the chance that serendipitous discoveries will be made, and that innovative solutions to problems will be found. By creating an environment that fosters innovation CSIRO provides a great source of value to Australia.

SOURCE: ACIL ALLEN CONSULTING

The benefits shown in **Box ES 1** are considerable. ACIL Allen argues that CSIRO is involved in leading edge research that seeks to address some of the most important challenges currently facing the economy and our society; and it is therefore entirely reasonable to expect that the impact and value of successful research outputs will be considerable over time. Furthermore, given that the estimated benefits are based on a small sample of thousands of CSIRO's projects, it is likely that the full value of CSIRO is considerably greater.

ACIL Allen adopted a two pronged approach to the task. First, we used the results of a large number of past case studies conducted by ACIL Allen and others to develop a conservative and robust quantified 'base line' estimate of the value delivered by CSIRO.

This approach builds on past case study analysis done by ACIL Allen and others. The approach allows robust and defensible conclusions about the impact and value delivered by CSIRO to be drawn from these case studies.

- Second, we examined six additional ways in which CSIRO has the scope to deliver value, namely:
 - The value of CSIRO's standing capacity.
 - The options created by CSIRO's research.
 - The training and education services that CSIRO provides.
 - The support that CSIRO provides for STEM education.
 - The royalties the CSIRO generates.
 - The collaborations that CSIRO has engendered.

ACIL Allen reviewed the relevant literature to identify the latest academic thinking about the potential value delivered by each of these areas. We also considered how the various case studies could inform us about the nature and scale of any possible benefits. While the benefits of these other sources of value are difficult to quantify, the literature reviews and information from the case studies support an argument that the scale of the estimated benefits from CSIRO's activities in these areas is likely to be considerable. In short, the qualitative discussion provides additional confidence that the estimate of the scale of the quantified benefit delivered by CSIRO is robust and defensible.

Some benefits from CSIRO's research are clear and quantifiable. For example, there is certainty around the income from royalties and licence fees that CSIRO has received. However, it is important to understand that many of the benefits from CSIRO's research lie in the future; and it is necessary to make a range of assumptions in order to quantify these benefits. ACIL Allen's approach is to be fully transparent about all of our assumptions

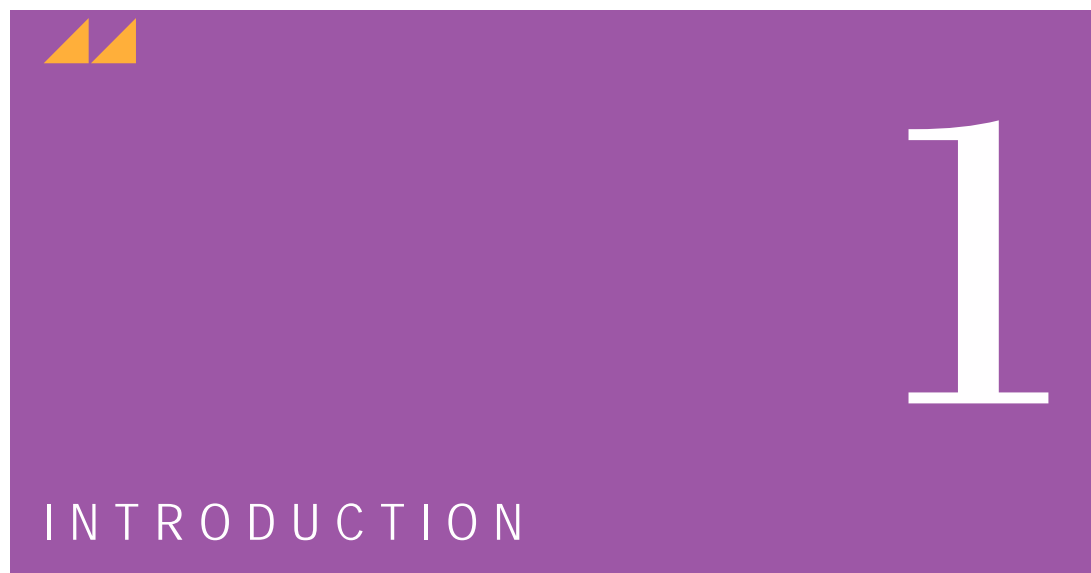
ACIL Allen seeks to ensure that all our assumptions are reasonable and defensible. Our review of the assumptions made for a sample of three previous case studies found that some of the original assumptions were overly conservative whereas others were optimistic. However, ACIL Allen found that the differences between the initial assumptions and what ultimately occurred were such that the impact on the size of the estimated benefits of the three case studies was unlikely to be significant.

There are also areas of scientific investigation by CSIRO of issues that are important to the national interest, but where economic gain may not be foreseeable. Institutions like the CSIRO play a valuable role by informing public policy. This type of information is particularly significant in areas of high complexity and uncertainty, such as the environment. It is important to recognise that it is highly unlikely that the private sector would invest in such research.

Future economic benefits are usually spread over many years, ACIL Allen generally seeks to express net benefits in Net Present Value (NPV) terms. This provides an aggregated value of benefits in excess of costs over time in today's dollars. Using NPVs allows comparison of the economic benefits from different case studies with different time lines and cost structures. NPVs are calculated by applying an annual discount factor to future benefits (in this report 7 per cent) to reflect the time value of money.¹ It is important to recognise that the estimated NPV of a research project is not a price that a buyer might pay for the rights to the research outcome today.

Finally, we have considered how CSIRO's structure and operations creates a culture within the organisation which enhances the likelihood of serendipitous discovery and innovation occurring. We suggest that CSIRO's ability to catalyse innovation in this way provides a great source of value to Australia.

¹ The discount rate reflects the fact that money available now is worth more than the same amount in the future due to its potential earning capacity.



1.1 Background

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) is Australia's largest scientific research organisation, and one of the largest and most diverse scientific organisations in the World.

Working from sites across Australia and around the globe, CSIRO seeks to provide new ways to improve the quality of life for all Australians, as well as the economic and social performance of Australian industries. CSIRO's research and development has delivered technology solutions that meet the needs of businesses across the economy, including the mining, agriculture, manufacturing, and services sectors. This has enabled those industries to innovate and improve their competitiveness and helped them to prosper and grow.

CSIRO's research on health issues has delivered treatments for illnesses or injury as well as approaches for preventing disease, vastly improving the quality of life of Australians and people around the world. CSIRO's science and modelling skills have provided insights that have helped the nation to improve the sustainability of our economy and better protect our environment.

CSIRO is an independent statutory authority constituted and operating under the provisions of the Science and Industry Research Act 1949 and the Commonwealth Authorities and Companies Act 1997. The Commonwealth Government provides significant funding to CSIRO. Consequently CSIRO, needs to demonstrate that it generates an appropriate level of benefits as a result of that investment of public funds.

1.2 Purpose of report

CSIRO has commissioned ACIL Allen to prepare an assessment of CSIRO's value. The project is intended to be an update of a similar assessment prepared in 2014.

The objectives of the project are:

...to provide a contemporary estimate of the benefit-cost ratio for investment in CSIRO and contextualise this in the organisation's overall value.

The task is expected to include:

Developing and applying a suitable methodology to estimate the benefit-cost ratio of investment in CSIRO by drawing on:

- The results of previous Impact Case Studies
- The results of previous Impact and Value assessments
- CSIRO'S Impact Evaluation Principles, as listed in CSIRO's Impact Evaluation Guide.

Providing a summary of the role and value of CSIRO, which details the qualitative value of CSIRO beyond a simple aggregation of previous case studies. This is expected to include:

- Exploring and (where possible) quantifying, the ways that CSIRO contributes to the innovation system
- Identifying insights gained from case studies undertaken to date.

1.3 Approach used to estimate the value of CSIRO

ACIL Allen has adopted a two stage approach towards estimating the value of CSIRO. The first stage involves quantifying the value by drawing on the results of a large number of case studies. The results of the case studies have been brought up to date by ensuring that the results are all expressed in 2016-17 dollars. The results of as many as possible of the existing case studies were aggregated to develop a base line estimate of the value of CSIRO's research.

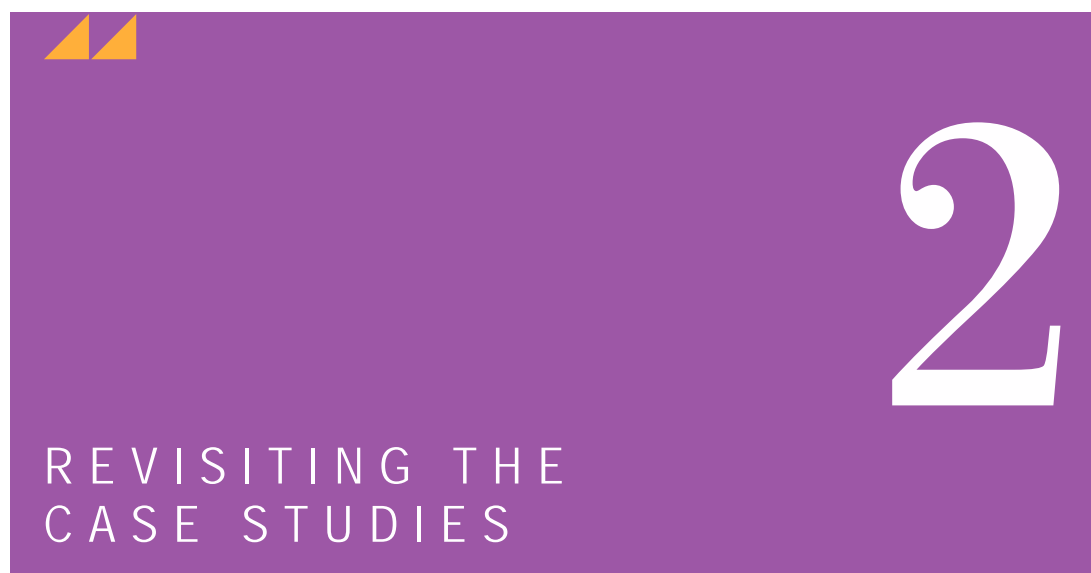
We assessed three of the previous case studies to see how well the assumptions made to prepare the initial estimates of benefits have stood up to the passage of time – in effect, to assess whether those assumptions are now seen as overly optimistic, too conservative, or still reasonable.

ACIL Allen has also mapped the information already collected for all the case studies against a set of agreed indicators. The aim of this mapping was to try to help extend the performance of the case studies to the performance of the CSIRO as a whole; and to identify which case studies provided supporting evidence for the potential value delivered through other pathways.

The second stage involves a qualitative assessment of six other pathways through which CSIRO can potentially deliver value. The other sources of potential value we have examined are:

- The value of standing capacity.
- The options created by CSIRO's research.
- The training and education services that CSIRO provides.
- The support that CSIRO provides for STEM education.
- The royalties the CSIRO generates.
- The collaborations that CSIRO has engendered.

For each of these pathways we have conducted a short literature review to identify the latest thinking on these sources of potential value and whether it is possible to quantify the benefits associated with each of them. We have also considered what the case studies can tell us about each of these pathways.



This Section revisits the case studies of CSIRO research projects prepared to date. The focus of the analysis is on case studies prepared by independent external reviewers, although a small number of internal case studies are included to help provide a more complete picture of CSIRO's research. The case studies that are considered in this report are shown in **Table 2.1**.

TABLE 2.1 CASE STUDIES EXAMINED

Name of Case Study	Author of Case Study	Comment
Agricultural Production System sIMulator (APSIM)	ACIL Tasman	
AuScope	Deloitte Access Economics (DAE)	
Australian Animal Health Laboratory (AAHL)	ACIL Allen	
Atlantic Salmon Breeding	CSIRO	
BARLEYmax	DAE	
Biochar	ACIL Tasman	
Botanical Resources Australia (BRA)	ACIL Allen	
BlueLink	ACIL Allen	
Bushfire research	ACIL Tasman	Part of the Climate Adaptation Flagship case study
Cement substitutes and novel products	ACIL Tasman	
Cereal Rust	CSIRO	
Climate Ready crops	ACIL Tasman	Part of the Climate Adaptation Flagship case study
Clinical Terminology Tools	DAE	
Coastal Communities	ACIL Tasman	Part of the Climate Adaptation Flagship case study
Cotton	ACIL Allen	
Distal Footprints	ACIL Allen	a SIEF case study
Early Nutrition	ACIL Allen	a SIEF case study
Energy Waste	ACIL Allen	a SIEF case study
eReefs	ACIL Allen	

Name of Case Study	Author of Case Study	Comment
Grapevine breeding	CSIRO	
Integrated Water Resource Assessments	ACIL Allen	
Longwall mining	ACIL Allen	
Mapping undersea minerals deposits	ACIL Tasman	
Medical Developments International (MDI)	ACIL Allen	
OptiCOOL (Building IQ)	ACIL Allen	
Plant Breeding	ACIL Allen	This was a SIEF case study
Prawn Breeding and Novel Feed	ACIL Allen	An earlier case study was done in 2009
Radioastronomy and the SKA	ACIL Tasman	
RAFT	ACIL Allen	This was a SIEF case study
Resistant starch grains	ACIL Tasman	There is an overlap with the DAE BARLEYmax case study
Scientists and Mathematicians in Schools (SMiS)	CSIRO	Valuation based on a Social Return on Investment (SROI)
Sustainable Commercial Fisheries	DAE	There is an overlap with the BlueLink case study.
Synchrotron	ACIL Allen	This was a SIEF case study
Textor	ACIL Allen	
Titanium	ACIL Tasman	Possibly more relevant as a lead in to the titanium 3D printing work now being done.
UltraBattery	ACIL Tasman	
Yield Profit	CSIRO	

SOURCE: ACIL ALLEN

2.1 Mapping the case studies

ACIL Allen has reviewed the information presented in the case studies listed in **Table 2.1** and mapped that information against a set of agreed indicators. The selected indicators were discussed and agreed with CSIRO. The agreed indicators were:

- Alignment with National Science and Research Priorities, namely:
 - Food
 - Soil and water
 - Transport
 - Cybersecurity
 - Energy
 - Resources
 - Advanced manufacturing
 - Environmental change
 - Health
- Number of publications
- Collaborators (number and type (business, university, research organisation, (Australian or overseas))
- CSIRO and external support provided (proportion of total funding from external sources)
- Number of PhDs trained
- Number of research disciplines on the research team
- Did the project contribute to policy development?

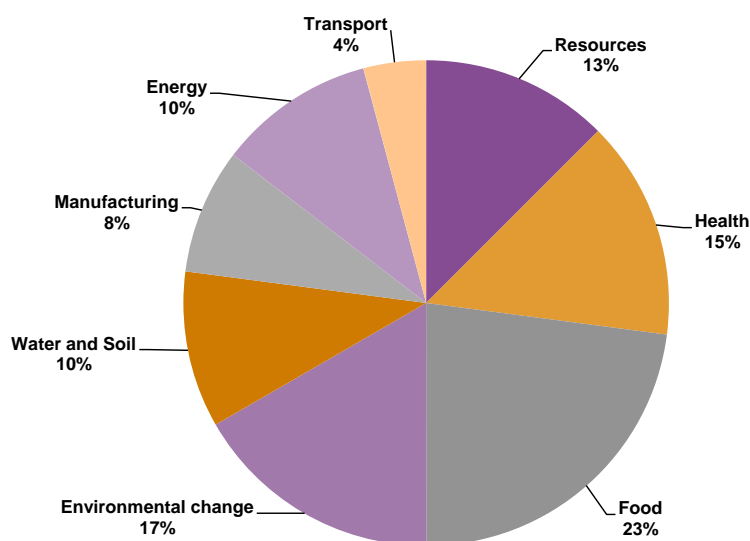
- Has research been commercialised or is it being commercialised?
- Nature, scale and timing of benefits.

The purpose of the mapping exercise is to identify information that can help us understand the extent to which it is possible to extend the finding regarding the performance of the case studies to the performance of the CSIRO research portfolio as a whole. We also seek to compare CSIRO's performance to that of the research community more broadly.

The results of that mapping are shown in **Table 2.2**. It is important to understand that we have relied solely on the information presented in the original case studies to complete the table. In a number of cases there were gaps in the available information. However, due to constraints on the time and resources for this evaluation we have not sought to fill those gaps.

We see from **Figure 2.1** that the case studies all align closely to one or more of the National Science and Research Priorities. Twenty-eight case studies align with one of the priorities, two align with two priorities and two align with three or more priorities.

FIGURE 2.1 CASE STUDY ALIGNMENT WITH NATIONAL SCIENCE & RESEARCH PRIORITIES



Note: A number of case studies align with more than one priority.

SOURCE: ACIL ALLEN

TABLE 2.2 MAPPING OF SELECTED CASE STUDIES

Project	Alignment with Science & Research Priorities	Publications	Collaborators	Support	Number of PhDs trained	Team research disciplines	Contribution to policy development?	Commercialisation	Nature of benefits
AuScope	Yes (<i>Resources</i>)	na	Geoscience Aust, 11 universities, & state govt. agencies	CSIRO	na	Geoscience, ICT	Possibly	Benefits flow direct to industry	<i>Economic</i> \$444.5m
Australian Animal Health Laboratory (AAHL)	Yes (<i>Health, Food</i>)	na	Many in Australia and overseas	CSIRO \$60.4m in FY 2014	na	Bioscience, medicine	Yes	na	<i>Economic</i> \$49b for Foot & Mouth Disease alone (also cost of other animal diseases avoided), <i>Environment</i> (protecting biodiversity), social (protecting health, employment).
Atlantic Salmon Breeding	Yes (<i>Food</i>)	na	Salmon Enterprises of Tasmania	CSIRO \$1.9m, SALTAS \$6.7m (2015-16 \$s) including in-kind		Bioscience	No	Benefits to industry	<i>Economic</i> \$170m (reduction in amoebic gill disease, increased harvest), <i>Environment</i> (reduced fresh water consumption), <i>Social</i> (regional employment)
BARLEYmax	Yes (<i>Health</i>)	na	GRDC, LCI	CSIRO \$28.2m, GRDC and LCI \$23.8m (2010 \$s)	na	Plant biology	No	Yes, Spin-out company, under licence agreement with CSIRO	<i>Economic</i> benefits to growers <i>Social</i> (health cost savings) (DAE 2014)
Biochar	Yes (<i>Environmental change</i>)	na	?	CSIRO, Commonwealth Dept. of Agriculture Forestry & Fisheries, GRDC	na	na	No	None identified	Limited benefits identified

Project	Alignment with Science & Research Priorities	Publications	Collaborators	Support	Number of PhDs trained	Team research disciplines	Contribution to policy development?	Commercialisation	Nature of benefits
Botanical Resources Aust. (BRA).	Yes (<i>Environmental change</i>)	2	BRA	CSIRO \$682k, BRA \$679k	na	Chemistry, chemical engineering	No	Through BRA	<i>Economic</i> (reduced post-harvest storage losses, veterinary applications), <i>Environment</i> (safer pesticides), <i>Social</i> (improved public health, regional employment).
BlueLink	Yes (<i>Resources</i>)	8	Bureau of Meteorology, Royal Australian Navy	RANin-kind; CSIRO \$16m, BoM \$x (2015-16 \$s)	na	Oceanography, ICT	Possibly	Results applied by industry and Defence	<i>Economic</i> \$25m (improved Navy, fishing industry & offshore oil/gas operations), <i>Social</i> (reduced drownings).
Bushfire research	Yes (<i>Transport</i>)	na	Bureau of Meteorology	CSIRO, Climate Institute, Bushfire CRC	na	Various	Yes (on building standards)	na	<i>Economic</i> (reduced losses from fire), <i>Environment</i> (reduced damage from fire), <i>Social</i> (improved fire truck & car safety)
Cement substitutes and novel products	Yes (<i>Environmental change</i>)	na	unspecified	CSIRO and other(s)	na	Chemical engineering	No	Unclear	<i>Economic</i> (new products), <i>Environment</i> (reduced greenhouse gases)
Cereal Rust	Yes (<i>Food</i>)	7	GRDC, 2Blades Foundation, ACIAR, CIMMYT, University of Sydney & University of Adelaide	CSIRO \$70.4m, CIMMYT \$4.2m, Sydney Uni \$4.2m	na	Plant breeding	No	Benefits to growers	<i>Economic</i> (increased productivity, fungicide costs avoided), <i>Environment</i> (reduced fungicides), <i>Social</i> (employment, food security)
Climate Ready crops	Yes (<i>Food</i>)	na		CSIRO, Dept of Agriculture, Forestry, Fisheries, GRDC	na	Plant breeding	No	Benefits to growers	<i>Economic</i> (drought resistance),

Project	Alignment with Science & Research Priorities	Publications	Collaborators	Support	Number of PhDs trained	Team research disciplines	Contribution to policy development?	Commercialisation	Nature of benefits
Clinical Terminology Tools	Yes (<i>Health</i>)	na	?	CSIRO	na	ICT	Yes	Not applicable	<i>Economic</i> (\$161.9m), <i>Social</i> (health)
Coastal Communities	Yes (<i>Environmental change</i>)	na	?	Commonwealth Govt. Sydney Coastal Councils		ICT, climate science	Yes	Used by local govt.	<i>Economic</i> (adaptation measures for cost avoidance)
Cotton varieties	Yes (<i>Environmental change, Soil & water</i>)	More than 40	Cotton Seed Distributors Ltd	CSIRO \$57.4m (2014 \$s)	na	Plant breeding	No	Benefits to industry	<i>Economic</i> \$379.5m (improved productivity, reduced need for pesticides), <i>Environment</i> (reduced insecticide contamination, reduced use of water), <i>Social</i> (sustainability of rural communities).
Distal Footprints	Yes (<i>Resources</i>)	4 plus 18 conference presentations	Industry partners Geol. Survey WA, Universities (UWA and Curtin)	SIEF \$4m, Geol. Survey WA \$2.5m, industry \$900k; in-kind from CSIRO \$2.1m, UWA \$1.9m, Curtin \$2.1m	4 PhD students & ECRs	Geoscience, geochemistry, ICT	Possibly	Possible	<i>Economic</i> \$19m (improved productivity, reduced exploration costs), <i>Environment</i> (avoided remediation costs)
Early Nutrition	Yes (<i>Health</i>)	na	WCHRI, Garvan, University of SA	SIEF \$5m: in-kind CSIRO \$7.4m, WCHRI \$2.3m, Garvan \$1.9m, Uni SA \$1.3m	na	Bioscience, medicine, nutrition, genomics	Yes	In livestock breeding, medical diagnostics	<i>Economic</i> \$422m (improved livestock reproduction), <i>Social</i> (better health)

Project	Alignment with Science & Research Priorities	Publications	Collaborators	Support	Number of PhDs trained	Team research disciplines	Contribution to policy development?	Commercialisation	Nature of benefits
Energy Waste	Yes (<i>Energy, Environmental change</i>)	87	ANSTO & five universities: (Monash, Melbourne, Sydney, Adelaide, NSW)	SIEF \$6m; in-kind Ansto \$1.7m, Monash \$1.4m, Uni Melb \$1.4m, Uni Sydney \$1.1m, Uni Adelaide \$819K, NSW \$715K	na	Chemistry, chemical engineering	No	Yes	<i>Economic</i> \$143m (new products and processes), <i>Social</i> (safety and health benefits)
eReefs	Yes (<i>Water & soil</i>)	17	AIMs, GBRF, Qld Govt.	SIEF \$4m, GBRF \$12.2m: in-kind CSIRO \$7.9m, AIMS \$1.2m, BoM \$5.4m	na	ICT	Yes	Used by government	<i>Economic</i> \$1.05b over 10 years (commercial fishing), environment (reef better managed), <i>Social</i> (tourism and recreations sustained)
Grapevine breeding	Yes (<i>Food</i>)	8	HAL (now HIA), DFRDC, WA, Qld and NT agencies	CSIRO \$37m, HIA \$4.7m, DFRDC \$1.6m	na	Plant breeding	No	Benefits to industry	<i>Economic</i> \$297.2m (new heat tolerant, higher yield, disease resistant grape varieties), <i>Social</i> (employment, stability of rural communities)
Integrated Water Resource Assessments	Yes (<i>Water & soil</i>)	Reports	Commonwealth & State govts.	CSIRO \$6.5m, externals \$47.7m	na	Water resource expertise	Yes	Benefits to landholders, governments	<i>Economic</i> >\$1.2b (best and more efficient use of water, optimising cropping choices, costs avoided e.g. reduced flooding), <i>Environment</i> (healthy rivers), <i>Social</i> (sustainable agricultural communities)
Longwall mining	Yes (<i>Resources</i>)	4 plus 21 conference papers	ACARP	ACARP \$6.6m, CSIRO \$1.6m cash and unspecified in-kind support	na	Mining engineering, geotechnical engineering, ICT, etc.	No		<i>Economic</i> \$785m (improved mining productivity), <i>Environment</i> (reduced footprint), <i>Social</i> (increased safety)

Project	Alignment with Science & Research Priorities	Publications	Collaborators	Support	Number of PhDs trained	Team research disciplines	Contribution to policy development?	Commercialisation	Nature of benefits
Mapping undersea minerals deposits	Yes (<i>Resources</i>)	na	na	CSIRO	na	ICT	Possibly	Information provided to industry	<i>Economic</i> (additional mining opportunities may be identified)
Medical Developments Intl	Yes (<i>Advanced manufacturing</i>)	na	MDI	CSIRO	na	Chemical engineering	No	Yes, through MDI, with royalties to CSIRO	<i>Economic</i> (MDI), <i>Social</i> (patient well-being)
OptiCOOL (Building IQ)	Yes (<i>Energy</i>)	5 key publications	na	CSIRO	na	Engineering, ICT	No	Yes, IP transferred to BuildingIQ	<i>Economic</i> \$79m over 10 years (efficiency gains, greater grid stability with decreased peak demand), <i>Environment</i> (reduced greenhouse emissions), <i>Social</i> (employee comfort)
Plant Breeding	Yes (<i>Food</i>)	11 (4 in high impact journals)	1 business, 2 Australian unis, 2 O/S institutes	SIEF \$4.5m, CSIRO \$3.2m	5 Postdocs	Plant biology	No	Yes, Commercial partners engaged	[From 2033] <i>Economic</i> \$2.8b (farmers), <i>Social</i> (food production)
Prawn Breeding and Novel Feed	Yes (<i>Food</i>)	3 (examples)	?	CSIRO \$22m, "external" \$4.5m; unspecified CSIRO in-kind support, external in-kind support \$1.7m	na	Molecular biology, prawn breeding, ICT	No	Yes, benefits to aquaculture industry	<i>Economic</i> \$452.5m (improved productivity & competitiveness, improved breeding, virus detection kits, improved prawn feed), <i>Environment</i> (reduced use of fish meal/oil inputs, reduced waste), <i>Social</i> (cheaper better prawns, employment).

Project	Alignment with Science & Research Priorities	Publications	Collaborators	Support	Number of PhDs trained	Team research disciplines	Contribution to policy development?	Commercialisation	Nature of benefits
RAFT	Yes (<i>Health</i>)	6 significant publications	2 businesses, 2 research organisations	SIEF \$4m, CSIRO \$5.7m, O'Brien Inst \$435k, Cochlear \$240k, University of Washington \$129k	na	Chemistry, biochemistry, biomedicine	No	Two commercialisation pathways	From 2029, <i>Economic</i> \$48.4m (new medical products), <i>Social</i> (lives saved)
Scientists and Mathematicians in Schools (SMiS)	Yes (<i>Potentially across all priorities</i>)	na	Commonwealth Govt., volunteers	Commonwealth Govt. \$7.9m, CSIRO \$1.3m; in-kind (volunteers) \$2.4m	na	Many disciplines	Possibly	na	<i>Social value</i> \$44m (changes in attitude to STEM, strengthened teaching, increased understanding of community perceptions, curriculum improvements).
Sustainable Commercial Fisheries	Yes (<i>Food</i>)	na	None	CSIRO	na	Marine biology, ecology	Yes	Not applicable	<i>Economic</i> (reduced effort per catch), <i>Environment</i> (reduced adverse ecological impact), <i>Social</i> (long-term sustainability of fishing industry & resilience of fishing communities) (DAE 2014)

Project	Alignment with Science & Research Priorities	Publications	Collaborators	Support	Number of PhDs trained	Team research disciplines	Contribution to policy development?	Commercialisation	Nature of benefits
Synchrotron	Yes (<i>Advanced manufacturing, Energy, Environmental change, Food, Health, Resources, Soil & water</i>)	260	Many in business, universities & institutes	SIEF \$10m, CSIRO \$230k	Many	Many	na	Various	Wide ranging economic, environment and social benefits
Textor	Yes (<i>Advanced manufacturing</i>)	na	Textor	Researchers in Business Program \$100k, CSIRO \$643k, Textor 451k; in-kind CSIRO \$1.2m	na	Engineering	No	Yes Through supply to Kimberly-Clark	<i>Economic</i> (to Textor) <i>Social</i> (benefits for new mothers)
Titanium		na						None, but skills and experience utilised in developing 3D printing using Titanium.	<i>Economic</i> (new production process for Ti metal),
UltraBattery	Yes (<i>Energy</i>)	na						Commercialisation being investigated	New battery and capacitor technology

Project	Alignment with Science & Research Priorities	Publications	Collaborators	Support	Number of PhDs trained	Team research disciplines	Contribution to policy development?	Commercialisation	Nature of benefits
Yield Prophet	Yes (<i>Food</i>)	Report	Birchip Cropping Group, Commonwealth Dept of Agriculture, Fisheries & Forestry, Qld Dept Agriculture & Fisheries, GRDC, Cropfacts P/L	CSIRO \$1.5m, Birchip Cropping Group \$2.94m, others \$1.86m	na	ICT, agriculture	Possibly	Web-based services by subscription to growers	Economic (improved productivity from real time soil, crop & climate data for growers), environment (better decisions on fertiliser/biocide use), social (regional employment)

Note: Some case studies list a sample of publications rather than a complete list. In some case studies, direct and indirect support contributions are combined. Values of support provided are as reported in the case studies and have not been adjusted to 2017 dollars. While it is likely that most projects involved some PhD training, this has been reported only in a few cases. The team research disciplines listed are the major contributors—most projects required a range of disciplines. Information about commercialisation is based on the information in the case studies.

SOURCE: ACIL ALLEN CONSULTING. SCIENCE AND RESEARCH PRIORITIES ARE SOURCED FROM [HTTP://SCIENCE.GOV.AU/SCIENCEGOV/SCIENCEANDRESEARCHPRIORITIES/PAGES/DEFAULT.ASPX](http://science.gov.au/sciencegov/scienceandresearchpriorities/pages/default.aspx)

2.2 Review of assumptions for selected case studies

As part of undertaking the cost benefit analysis for previous case studies ACIL Allen made a number of assumptions about a range of factors, including:

- The market for the new technology developed by CSIRO.
- The timing and rate of take up of new technologies.
- The timing and nature of benefits.
- The attribution of benefits to CSIRO.
- The counterfactual in the event that CSIRO had not undertaken the research technology.

ACIL Allen is always transparent in specifying the assumptions we make. We also seek to be as conservative in those assumptions as possible. Nonetheless, any assumption by its very nature has some uncertainty attached to it. This is particularly so for CBAs that are based on preliminary estimates of values for various key inputs, which make the results necessarily provisional on how well assumptions match reality over time.

For this study we have reviewed the assumptions made for three previous case studies. Our objective was to assess whether the original assumptions made for the CBAs on those case studies are now seen as overly optimistic, too pessimistic, or still about right.

The following three case studies were selected as candidates for this review:

- The Cotton Varieties Case Study
- The Resistant Starch Grains Case Study
- The Prawn Breeding and Prawn Feed Supplement Case Study

With the assistance of CSIRO, a series of meetings was arranged with research leaders from each of these projects in order to discuss and review the assumptions used in the original case study. The results of each of those discussions is summarised below.

2.2.1 Review of the Cotton Varieties case study assumptions

This case study was originally prepared in 2014. The key findings of the case study are summarised in **Box 2.1**.

ACIL Allen reviewed the assumptions made as part of the original case study in order to estimate the benefits of this research project. To do this we spoke to researchers involved in the project at the time of the original case study as well researchers currently working on this project.

New varieties are expected to continue to replace older varieties over time. The conversation revealed a number of conflicting influences on the scale of the benefits from this project. CSIRO's research into new cotton varieties is continuing.

The share of the US market held by CSIRO varieties has varied over time due to weather conditions and competition from other varieties, but royalty payments have nonetheless increased. There has also been some growth in the sales of CSIRO varieties in the Brazilian market. Consequently the returns to CSIRO are expected to grow.

The assumptions in 2014 about the growth in yield over time are still seen as reasonable, although the researchers noted that yield is gradually getting closer to the theoretical yield maximum. The assumptions regarding future cotton prices are also seen as reasonable.

The assumption in 2014 that the total area of land in Australia under cotton cultivation would not exceed 300,000 ha is now seen as too low.

The researchers had no data that would enable them to test the assumptions regarding the extent to which improvements in yield could be attributed to the genetic breeding undertaken by CSIRO. However, they noted that conversations with growers suggested that they were able to get more yield out of newer varieties through the integration between those varieties and improved management systems. In addition, around three quarters of the growers the researchers have spoken to report that the new varieties are providing increased yield.

BOX 2.1 KEY FINDINGS OF THE COTTON VARIETIES CASE STUDY

The 2014 case study found that CSIRO's cotton breeding research project:

- Had delivered net benefits to Australia of approximately \$149.3 million in 2014 dollar terms between 2006/7 and 2013/14, representing an internal rate of return of 93 per cent over original input costs.
 - ACIL Allen estimated future benefits of over \$379.5 million over the following decade under a 5 per cent discount rate as a result of cotton yield productivity increases due to CSIRO's research project.
- Had increased the productivity of Australia's cotton farms due to the breeding of cotton varieties that are more resistant to common diseases, ore water efficient, and better adapted to Australian weather and soil conditions.
- Had provided a number of other important benefits. These were not included in the cost-benefit calculations, but have nonetheless delivered benefits to Australia over the lifespan of CSIRO's cotton varieties research project. These benefits included:
 - Improved ecological health and lower exposure of farmers and farming communities to pesticides as a result of reduced pesticide use.
 - Increased water efficiency – Australian cotton farming is now the most water-efficient in the world.
 - Increased sustainability of local farming communities, due to the increased resilience of the cotton industry to risks such as disease and drought.

SOURCE: REPORT ON CSIRO'S IMPACT AND VALUE, ACIL ALLEN, DECEMBER 2014

Conclusion

Based on our discussions with the researchers ACIL Allen believes that most of the assumptions made in 2014 remain reasonable and, in some cases, they may be overly conservative. Hence the benefits of this project could possibly be greater than was originally estimated in 2014.

2.2.2 Review of the Resistant Starch Grains case study assumptions

This case study was originally prepared in 2010. The key findings of the case study are summarised in **Box 2.2**.

ACIL Allen reviewed the assumptions made as part of the original case study in order to estimate the benefits of this research project. To do this we spoke to researchers involved in the project at the time of the original case study as well researchers currently working on this project.

BOX 2.2 KEY FINDINGS OF THE RESISTANT STARCH GRAINS CASE STUDY

The 2010 case study found that CSIRO's resistant starch grains research project:

- Had led to a patented form of barley (BARLEYmax) which had high levels of resistant starch and had used the knowledge gained to develop a high amylose wheat that was expected to be commercialised by 2013.
- Could lead to estimated benefits as high as \$554 million. The major driver of these benefits were the savings in years of life lost to disease and the savings of years of Australian lives lived with disease. This estimate did not allow for:
 - any premium on the processed food produced from these grains
 - the option value of being able to transfer the same knowledge to other crops such as rice
 - any royalties or license fees associated with exports or licences to overseas grain growers or food producers.

SOURCE: ASSESSMENT OF CSIRO IMPACT AND VALUE, ACIL TASMAN, 2010

The researchers advised that the rate of uptake of the two grains developed by CSIRO had been slower than expected. However interest in the grains remained strong. A Japanese company has taken an equity position in the Australia based licensee of the BARLEYmax technology and a significant number of BARLEYmax products are now being released in the Japanese market. .

Researchers have sought to make high amylose rice, but the research has had limited success to date. Other researchers are seeking to do similar work, however CSIRO's patents on the technology will make it hard for competitors to catch up with CSIRO. One researcher noted that it would be very hard for competitors to demonstrate 'novelty' in their research. This suggests that the 2010 assumption that an alternative product would be on the market in five years is too short a period.

The researchers believe the assumptions regarding the health benefits of resistant starch grains remain reasonable. There is evidence emerging that the health benefits of the grains in combatting colorectal cancers might be higher than was estimated in 2010. There are also indications that these grains have the potential to improve human health outcomes in other areas, such as inflammatory bowel, Parkinson's, and Alzheimer's diseases.

The current health guidelines specify a target of 15 grams of fibre per day per person. This would equate to some 1.2 million tonnes of grain a year for Australia. This is more than an order of magnitude greater than was estimated in the 2010 case study (namely 100,000 tonnes). Of course there are other sources of fibre and grain does not need to supply all the dietary fibre required.

The volumes of BARLEYmax grown have been less than was anticipated in 2010. The volume of BARLEYmax grown is not expected to reach the 25,000 tonnes that in 2010 were estimated to be grown by 2015 until 2027. The delays in production of BARLEYmax were in part due to delays in negotiating commercial arrangements. Those issues have now been addressed and there are currently good prospects for the Asian market (China and Japan); and the process is underway to begin production in the US and European markets by around 2020.

In 2010 ACIL Tasman estimated that BARLEYmax would provide a growers premium of around \$50 a tonne. This now appears to be a significant underestimate as grower premiums are closer to five times that amount. Even allowing for the fact that the yield of

BARLEYmax is some 55 to 75 per cent less than conventional barley, this suggests that a grower premium of around twice the amount assumed in 2010 would be reasonable.

CSIRO does not receive royalties or licence fees for BARLEYmax. Rather it has taken around 30 per cent equity in the firm commercialising the grain. It is anticipated that a return on investment for the research into BARLEYmax will flow through an appreciation in value of the firm.

The production of HA Wheat has also been slower than expected. The figure of 100,000 tonnes is now projected to be achieved by around 2023 (rather than 2017 as was originally expected). As with BARLEYmax, the delays are in part due challenges in finalising arrangements with commercial partners. However production of HA Wheat is now projected to continue to increase rather than plateau, reaching 200,000 tonnes by 2025 and 300,000 tonnes by 2028. This is due to the projected production of the HA Wheat in the US, Asian and European markets.

In 2010 ACIL Tasman estimated that HA Wheat would provide a growers premium of around \$50 a tonne. Based on the substantial royalty that is expected to be paid to Arista (the spin off firm set up by CSIRO to market the new wheat strains), ACIL Allen expects that the growers' premium would be above the earlier estimate. CSIRO retains a significant level of equity in Arista. It is anticipated that a return on investment for the research into HA Wheat will be delivered through an appreciation in value of the firm and or dividend payments.

For the 2010 case study ACIL Allen assumed that competitors would enter the market within five years and the market share of HA Wheat would therefore slowly decline. This now would appear to be an overly pessimistic assumption. The patent protection for the grain is seen as very strong, with a recent patent expected to provide protection until 2029.

Conclusion

There have undoubtedly been a delay in achieving the production figures projected in 2010 for BARLEYmax. However, the commercialisation of the grain now appears to be back on track. On the plus side, the grower's premium appears to be at least twice the number estimated in 2010. In addition, the health benefits for some of the diseases considered in 2010 are now thought to possibly be greater than estimated at the time. There is also a suggestion that BARLEYmax may provide health benefits for a number of other serious and/or chronic diseases. Finally, the assumption in 2010 that there would be alternatives to BARLEYmax on the market within five years now seems to be pessimistic

On balance, ACIL Allen believes that the 2010 estimation of the benefits in the medium term from BARLEYmax could be somewhat less than thought at the time. However, in the longer term there are certainly prospects for the benefits to be significantly greater.

The situation for HA Wheat is similar to that of BARLEYmax in that while the benefits will be slower to arrive, there is a strong likelihood that they could be significantly greater in the longer term.

2.2.3 Review of the Prawn Breeding and Prawn Feed Supplement case study assumptions

This case study was originally prepared in 2014. The key findings of the case study are summarised in **Box 2.3**.

ACIL Allen reviewed the assumptions made as part of the original case study in order to estimate the benefits of this research project. To do this we spoke to researchers involved in the project at the time of the original case study as well researchers currently working on this project.

Those conversations revealed that there had been a delay in the delivery of the benefits from the novel prawn feed developed as part of this project compared to the assumptions in the original case study. One reason for the delay has been the difficulties experienced in scaling up the process for manufacturing the prawn feed. CSIRO has worked closely with the firms licensed to manufacture the feed to overcome those difficulties. Other reasons for the delay include:

- Regulations around the fibre content of food provided to prawns (the CSIRO prawn feed is high in fibre).
- Delays in identifying a suitable site for manufacturing the prawn food (the production facility is now operational, but it took four years to find a suitable site).
- An outbreak of disease in prawn farms in Asia also contributed to the delay.

However royalty revenue has begun to flow; and ACIL Allen estimates that the amount of royalties from the prawn breeding and prawn feed will largely match those in the original case study, only with a delay of around four years.

BOX 2.3 KEY FINDINGS OF PRAWN FEED AND BREEDING CASE STUDY

The 2014 case study found that CSIRO's research and development on prawn breeding and feed had led to:

— Improved productivity

- Prawns that grow faster, have a more consistent size and are more resistant to common viruses.
- Ponds stocked with CSIRO's selectively bred prawn broodstock had a 39 per cent increase in productivity compared to ponds stocked with wild stock.

— A more sustainable prawn industry

- The prawn feed additive Novacq™ is made using agricultural waste and removes the need to use fish meal or fish oil obtained from the wild fish resources.
- Prawns that are fed the additive are healthier and grow 30-40 per cent faster.

The uptake of the new prawn breeds had been rapid and significant at the time and was expected to track the projected expansion in the industry. Benefits delivered to the industry as at 2014 were estimated to be around \$73.5 million. Of this, it was assumed that 75 per cent, or \$55.1 million, were attributable to CSIRO. ACIL Allen estimated that CSIRO's prawn breeding project would deliver total additional benefits of \$452.5 million under a 5 per cent discount rate between 2014 and 2023/24, of which 75 per cent or \$339.4 million was attributable to CSIRO.

Use of Novacq™ had only just begun so the benefits at the time were small. However there had been very strong interest in licensing the technology and this (plus the demonstrated benefits of the feed) was expected to drive strong uptake in Australia and overseas. ACIL Allen estimated that the cumulative benefits from the use of the novel prawn feed would be around \$368.3 under a 5 per cent discount rate between 2014 and 2023/24. In addition, CSIRO was expected to earn over \$100 million in royalties from the domestic and overseas sale of Novacq™.

This added up to total benefits of \$882.2 million attributable to CSIRO, including the revenue from royalties.

SOURCE: REPORT ON CSIRO'S IMPACT AND VALUE, ACIL ALLEN, DECEMBER 2014

The uptake of CSIRO's prawn broodstock in Australia has been dealt a major blow due to an outbreak of prawn disease and the resultant loss of CSIRO's prawn germ stock. However, there is still strong uptake among overseas prawn farmers, which is seen as the major element of the market.

There are a number of other positive messages to emerge from the discussions with the researchers on this project. For example, the researchers are now investigating the potential for the technology used to make the prawn feed to be used to produce food for farmed fin fish. It is estimated that the production of just 10 per cent of the food for fin fish farms in Vietnam using CSIRO's technology could generate as much as \$14 million a year in additional royalties. In addition, the prawn virus diagnostic kit that CSIRO developed as part of this research is expected to be commercialised this year.

CSIRO is not aware of any other researchers which have been able to produce prawn feed for a similar cost and quality. In addition, a new patent has recently been granted to CSIRO. It is the first patent for a feed that contains no fish oil or meal. This patent should serve to protect CSIRO's royalty stream for longer than previously expected.

The company commercialising the prawn feed have recently been granted a licence for the prawn feed manufacturing process for the rest of the world. As a result of this, the company

has recently announced that they plan to expand production and begin to manufacture prawn feed in Thailand.

Conclusion

Benefits from the adoption of CSIRO prawn broodstock in Australia will clearly be less than estimated. However, the overseas market is still strong, and is expected to remain so.

While there has been a delay in the receipt of royalty payments associated with the prawn feed research, they are still ultimately expected to largely match the levels assumed in the original case study. There also appears to be promising prospects for revenue growth and royalties to be higher and last for longer than originally assumed due to strong patent protection and a lack of success by other researchers in producing feed of a similar quality at a similar price. Potential new markets for feed for fin fish also suggest that there may be more upside to the estimate of benefits.

Based on the above, ACIL Allen believes that the benefits of this project may be somewhat less in the short to medium term than projected in the original case study. However, in the longer term, there is the potential for the benefits to be greater than originally estimated.

2.2.4 Conclusions of the review of case study assumptions

Nils Bohr is reported to have said:

Prediction is very difficult, especially if it's about the future.

Certainly the review of the assumptions made for three of the case studies has demonstrated the challenges around making assumptions about the future course of events. Several of the assumptions made for the case studies proved to be wrong as the actual course of events diverged from what was assumed would occur.

However, the review did demonstrate the merits of adopting assumptions that were both robust, in that they were based on careful consideration of the science and likely impact of research outcomes, and conservative. While the assumptions often diverged from what actually occurred, they were as likely to err on the side of being overly pessimistic as they were of being too optimistic.

While we have examined a relatively small sample of the case studies, the results provide us with confidence that the approach we have taken to estimating the impact and value of the case studies is reasonable, and on the balance of probability likely to provide what most would agree is a reasonable estimate of the lower bound for the value of CSIRO's research in the areas covered by the case studies.

2.3 Refresh of the Cost Benefit Analysis results from case studies undertaken since 2010

ACIL Allen has 'refreshed' the economic analysis component of CSIRO case studies undertaken since 2010 (by ACIL Tasman, ACIL Allen Consulting, Deloitte Access Economics, and internally by CSIRO) to bring the costs and benefits calculated up to date.

Costs and benefits have been recalculated in order for them to be expressed in a dollar value at a common point in time, namely in 2016-17 dollars, using the Consumer Price Index. Present value calculations of costs and benefits have also been harmonised so that

they have a common base year (2016-17) across the case studies. A real discount rate of 7 per cent has been assumed in these present value recalculations.

For several case studies (namely the Opticool Building IQ, MDI Pentrox, Cotton Varieties, and Prawn Breeding case studies undertaken by ACIL Allen), the original benefit valuation analyses have been converted into full-blown cost-benefit analyses.

It is important to emphasise that we have not sought to review the assumptions underpinning the case studies, with the exception of the three selected case studies discussed in Section 2.2.

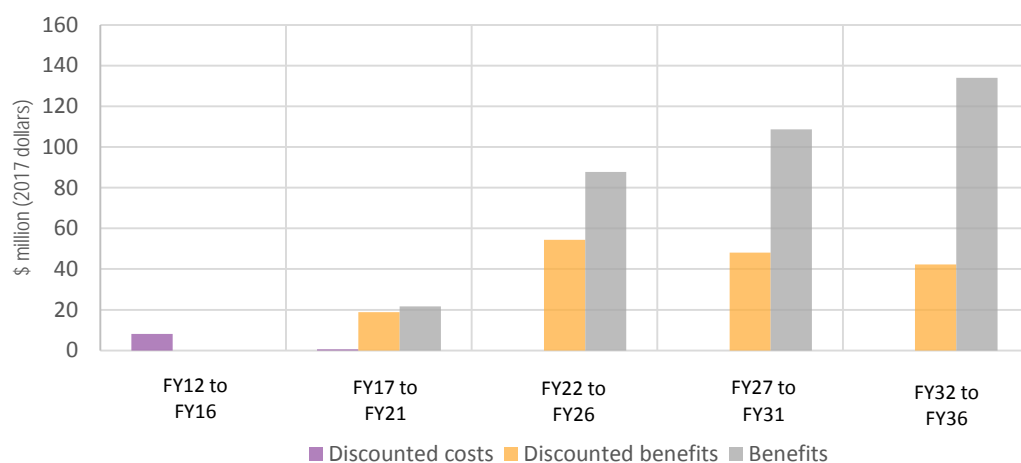
One key metric of a cost-benefit analysis is the Net Present Value (NPV). NPV is the difference between the present value of benefits and the present value of costs over the chosen analysis period (which varies between case studies) under the chosen discount rate (in this case 7 per cent). The discount rate is applied to reflect the fact that the value of a dollar in the future is less than it is now.

The costs considered in the cost-benefit analyses include the costs incurred by CSIRO and its research partners to produce the research outputs, such as staffing costs and in-kind contributions (including those relating to equipment/facilities and background intellectual property). Where data is available, usage and adoption costs borne by end-users (such as the costs of trials as well as costs associated with further development and market testing) are also included.

Benefits considered include the increased economic activity in Australia generated by the implementation of research findings, reduction in resource costs associated with existing economic activity, as well as the valuation of any health and environmental benefits that flow from the research undertaken by CSIRO and its collaborators.

As the costs and benefits are incurred and delivered at different points in time, they are converted to a common metric by discounting (at 7 per cent per annum in real terms). This is illustrated in **Figure 2.2**, which shows the discounted CSIRO costs as well as the discounted and undiscounted benefits in 5-year periods for the SIEF energy waste case study.

FIGURE 2.2 SIEF ENERGY WASTE CASE STUDY ESTIMATED BENEFITS (DISCOUNTED AND UNDISCOUNTED)



SOURCE: ACIL ALLEN CONSULTING

Table 2.3 presents a summary of the cost-benefit analysis results from the CSIRO case studies undertaken since 2010. Note that there were a number of case studies where formal quantification of benefits was not possible at the time they were undertaken due to data limitations or commercial confidentiality concerns, namely the Titanium, Textor, APSIM and Biochar case studies. These case studies are therefore omitted from the table.

TABLE 2.3 SUMMARY OF COST-BENEFIT ANALYSIS RESULTS FROM CSIRO CASE STUDIES UNDERTAKEN SINCE 2010

Case study	Analysis period		Benefits per year (2016/17\$m)	PV benefits (2016/17\$m)	PV costs (2016/17\$m)	NPV (2016/17\$m)	NPV (range) (2016/17\$m)
	Start year	End year					
ACIL Allen Consulting							
AAHL (Foot and Mouth Disease)	2008/09	?	475.1	3,336.9*	?	-	-
Integrated water resource assessments	2005/06	?	Varies	1,386.0	172.7	1,213.3	-
Cotton varieties	2006/07	2024/25	Varies	493.6	82.5	411.1	263.9 – 557.3
Bluelink	2003/04	2025/26	Varies	53.1	25.9	27.2	-21.1 – 106.1
Botanical Resources Australia	2003/04	2029/30	Varies	9.7	1.5	8.2	6.2 – 10.1
BuildingIQ	2006/07	2024-25	Varies	73.7	0.8	72.9	31.1 – 184.9
eReefs	2009/10	2025/26	Varies	96.8	9.1	87.2	6.3 – 271.5
Longwall automation	2001/02	2024/25	Varies	1,691.9	37.7	1,654.2	430.3 – 3,531.9
MDI Pentrox	2014/15	2029/30	Varies	200.1	0.7	199.4	137.2 – 433.5
Prawn breeding + Novacq feed	2004/05	2024/25	Varies	833.0	18.9	814.1	505.9 – 1,219.0
SIEF - Energy waste	2011/12	2035/36	Varies	151.6	7.3	144.3	114.8 – 182.3
SIEF - Early nutrition	2011/12	2035/36	Varies	2,838.1	6.2	2,831.9	2,086.0 – 2,933.6

Case study	Analysis period		Benefits per year	PV benefits	PV costs	NPV	NPV (range)
SIEF - Plant yield	2010/11	2035/36	Varies	3,001.6	6.2	2,995.4	1,958.7 – 5,205.4
SIEF - RAFT for medical applications	2011/12	2035/36	Varies	532.4	4.8	527.6	261.4 – 1,060.1
SIEF - Distal footprints	2012/13	2035/36	Varies	23.4	4.3	19.2	7.0 – 31.3
SIEF - Synchrotron	2012/13	2035/36	Varies	724.6	9.2	715.4	377.4 – 1,053.4
ACIL Tasman							
Climate Adaptation Flagship - 2006/07 coastal communities		2070?	Varies	374.6	16.9	357.7	-
Climate Adaptation Flagship - 2008/09 climate ready crops		2049/50	Varies	936.5	8.1	928.4	-
Cement substitutes and novel products	2000/01	?	Varies	125.5	37.5	88.0	-
Ultrabattery	2004	2020	Varies	71.0	9.4	61.6	-
Radioastronomy and the SKA ?		?	Varies	-	-	149.8	-
CSIRO							
Cereal rust	1994/95	2024/25	Varies	597.8	182.9	414.9	-
Grapevine breeding	1964/65	2024-25	Varies	362.9	40.2	322.8	-
Yield Prophet	1994/95	2034/35	Varies	10.3	3.4	7.0	-
Atlantic salmon breeding	2004/05	2024/25	Varies	88.6	3.4	85.4	-
Deloitte Access Economics							
BARLEYmax	-	-	266.0	1,868.3*	-	-	-
Sustainable commercial fisheries	-	-	415.9	2,921.1*	-	-	-
Clinical terminology tools	-	-	170.0	1,194.0*	-	-	-
AuScope	-	-	466.7	3,277.9*	-	-	-
All case studies where benefits have been quantified				27,275.0			

In some of the case studies, it is unclear what the start and/or end date of the analysis period was (identified by the “?” symbol in the table). Some case studies only reported the expected annual benefits of the project when full adoption of the research outcomes has been achieved. In one instance, only the expected net present value (NPV) of the project was provided in the case study. In still other cases, project costs were not reported in the case studies.

Ranges for the NPV metrics are provided in case studies where sensitivity analyses were undertaken when the case studies were originally prepared.

As can be seen in the table, the present value of benefits across the 28 case studies where benefits data was available is approximately \$27.3 billion in 2016/17 dollars under a 7 per cent real discount rate.

2.3.1 Estimated annualised benefits from CSIRO research compared operating expenditure

It is natural to think of CSIRO's total expenditures, across its whole portfolio, in annual terms, and to enquire as to the rate of return being achieved on that rolling annual investment. CSIRO's annual operating expenditure is of the order of \$1.27 billion, of which just over 60 per cent comes from appropriation, with the remainder being generated internally and coming from various partnering arrangements with industry and government agencies.² This section assesses the value that CSIRO delivers from this level of rolling investment.

CSIRO manages a large, diverse, and constantly evolving investment portfolio. It is assumed that this portfolio has evolved to a point of being reasonably stable in its performance characteristics through time. While some areas of research mature and research findings are disseminated to industry and other users, other areas do not live up to expectations and resources are redirected. New opportunities emerge or existing areas begin to show greater promise, resources are applied to these areas. However, over time, the outcome is a *rolling investment strategy* with a flow of benefits. While there will be occasional major breakthroughs of very high value, it is reasonable to characterise the CSIRO as having a portfolio that involves both an annual investment and an 'average' rate of benefit generation. Our objective is to assess whether these 'average' benefits support the level of investment being made.

The above logic can be applied down to the level of individual programs and the case studies undertaken in this review. Each of these investments involves investment over a number of years that can be translated to an average level of annual expenditure. Each case study yields impacts with value that will typically accumulate over many years into the future (and that has been calculated in present value terms). This block of value can similarly be translated into an average annual value created across the years of the activity being assessed.

For example, a four-year program that delivers an expected value of \$40 million over the next 10 years could be argued to have delivered average annual benefits of \$10 million per year of research undertaken. If we assume the program cost \$4 million, or \$1 million per year, then we could conclude that the average annual performance of the program was to deliver incremental value of \$10 million for an incremental cost of \$1 million, suggesting an average (annual) benefit-cost ratio of 10:1.

The assessment of average annualised benefits and costs allows for comparisons between programs operating over different time scales, and allows aggregation of average annual benefits and costs in a way that can be mapped directly into annual CSIRO expenditure.

Table 2.4 summarises the quantitative results of the case study assessments translated into the 'average' annual terms described above. Across the case studies, where data was available to enable the R&D costs and benefits to be annualised, the estimated total value of benefits generated per year is approximately \$3.2 billion. This amount, of course, reflects the case studies where data was available to develop an annualised benefit. The amount can reasonably be expected to have been substantially higher if data had been available for the other case studies. Similarly, if the benefits from other CSIRO research projects (which were not subjected to economic appraisal) were able to be included this would also increase the benefit number. Even so, the \$3.2 billion in quantified estimated annualised benefits is well in excess of CSIRO's annual operating expenditure of approximately \$1.27 billion.

² CSIRO Annual Report 2015-16

TABLE 2.4 ANNUALISED BENEFITS AND COSTS BY CASE STUDY, 7% DISCOUNT RATE

Case study	Analysis period		PV of benefits	PV of R&D costs	R&D period	R&D cost per year	PV of benefits per year of R&D
	Start year	End year	(2016/17\$m)	(2016/17\$m)	Years	(2016/17\$m)	(2016/17\$m)
ACIL Allen Consulting							
AAHL (Foot and Mouth Disease)	2008/09	-	3,336.9	340.0	5	68.00	667.38
Integrated water resource assessments	2005/06	-	1,386.0	172.7	8	6.80	173.25
Cotton varieties	2006/07	2024/25	493.6	82.5	9	9.17	54.84
Bluelink	2003/04	2025/26	53.1	25.9	12	2.16	4.43
Botanical Resources Australia	2003/04	2029/30	9.7	1.5	9	0.17	1.08
BuildingIQ	2006/07	2024-25	73.7	0.8	5	0.16	14.74
eReefs	2009/10	2025/26	96.8	9.1	4	2.28	24.20
Longwall automation	2001/02	2024/25	1,691.9	37.7	13	2.90	130.15
MDI Pentrox	2014/15	2029/30	200.1	0.7	-	-	-
Prawn breeding + Novacq feed	2004/05	2024/25	833.0	18.9	10	1.89	83.30
SIEF - Energy waste	2011/12	2035/36	151.6	7.3	6	1.22	25.27
SIEF - Early nutrition	2011/12	2035/36	2,838.1	6.2	5	1.24	567.62
SIEF - Plant yield	2010/11	2035/36	3,001.6	6.2	4	1.55	750.40
SIEF - RAFT for medical applications	2011/12	2035/36	532.4	4.8	6	0.80	88.73
SIEF - Distal footprints	2012/13	2035/36	23.4	4.3	6	0.72	3.90
SIEF - Synchrotron	2012/13	2035/36	724.6	9.2	3	3.07	241.53
ACIL Tasman							
Climate Adaptation Flagship - coastal communities	2006/07	2070?	374.6	16.9	5	3.38	74.92
Climate Adaptation Flagship - climate ready crops	2008/09	2049/50	936.5	8.1	4	2.03	234.13
Cement substitutes and novel products	2000/01	n.a.	125.5	37.5	10	3.75	12.55
Ultrabattery	2004	2020	71.0	9.4	6	1.57	11.83
Radioastronomy and the SKA	n.a.	n.a.	-	-	-	-	-
CSIRO							
Cereal rust	1994/95	2024/25	478.3	162.9	21	7.76	22.78
Grapevine breeding	1964/65	2024-25	362.9	40.2	n.a.		
Yield Prophet	1994/95	2034/35	10.3	3.4	21	0.16	0.49
Atlantic salmon breeding	2004/05	2024/25	88.6	3.4	7	0.49	12.66
Deloitte Access Economics							
BARLEYmax	n.a.	n.a.	1,868.3*	-	-	-	-
Sustainable commercial fisheries	n.a.	n.a.	2,921.1*	-	-	-	-
Clinical terminology tools	n.a.	n.a.	1,194.0*	-	-	-	-

Case study	Analysis period		PV of benefits	PV of R&D costs	R&D period	R&D cost per year	PV of benefits per year of R&D
AuScope	n.a.	n.a.	3,277.9*	-	-	-	-
All case studies where the available data enabled R&D costs and benefits to be annualised							3,200.17
<small>Note: * Assumes a 10-year period over which the annual benefits are realised. SOURCE: RECALCULATIONS BY ACIL ALLEN CONSULTING BASED ON CASE STUDIES ORIGINALLY UNDERTAKEN BY ACIL ALLEN CONSULTING, ACIL TASMAN, DELOITTE ACCESS ECONOMICS AND CSIRO</small>							

2.4 Value of other program activities

The case studies included in this review were ones that had been previously selected. A number of factors were considered in selecting them, including getting a reasonable spread of research projects across the portfolio of different research topics covered by CSIRO and seeking to illustrate the range of expertise that CSIRO has. ACIL Allen deliberately avoided a random sampling approach. If we had used such an approach it would have been necessary to select a much larger sample of projects to develop into case studies in order to arrive at conclusions that could be regarded as robust and defensible. This would have required a much larger and more costly review. Rather, the approach of selecting specific projects, allowed strong inferences to be drawn from a relatively modest number of case studies.

Many of the case studies have been discussed in previous ACIL Allen reports. Each of these reports (plus those by others) have argued that there is substantial value outside of the case studies specifically examined in the report in question. The fact that each subsequent report has in turn identified additional benefits strongly supports that argument and a finding that the same argument applies equally to this current review.

Based on the above, ACIL Allen believes that it is reasonable to assume that the annual value delivered by all other CSIRO research would at least match that delivered by the case studies considered in the analysis for this report. In which case, total annual benefits from CSIRO's research would exceed \$6 billion. By comparing this figure with CSIRO's annual operating expenditure of approximately \$1.27 billion, it implies that the expected ratio of return to CSIRO's research as a whole is around 5:1.

The figure of \$6 billion is subjective but, given the weight of evidence, ACIL Allen considers it to be conservative. For example, the four case studies in the Deloitte Access Economics review, which were not included in the annualised case study benefits estimated above, identified benefits attributable to CSIRO of some \$1.32 billion a year.

2.5 Findings

ACIL Allen has reviewed 34 past case studies that have each examined the impact and value of a CSIRO research project. Our aim was to develop a contemporary estimate of the value delivered by CSIRO.

The approach used in developing the case studies has varied over time. Hence the available financial information and how it was presented is not consistent across all the case studies. Therefore not all the case studies could be used to estimate the lower bound for the

value of the CSIRO. However there were 28 case studies with sufficient information to be able to confidently estimate the benefits of the associated research. ACIL Allen has estimated the present value of benefits of those 28 case studies to be around \$27.3 billion in 2016/17 dollars under a 7 per cent real discount rate. ACIL Allen believes that this estimate provides a robust lower bound for the overall present value delivered by the organisation.

Over the period from 1978-79 to 2016-17 the Australian Government has supported CSIRO's research and development by providing just under \$14 billion in funding (in 2016/17 dollars). The estimated benefits from 28 research projects alone is almost twice this amount.

ACIL Tasman's 2010 estimate of the value of CSIRO argued that:³

...that the value of CSIRO's impact across the entire research portfolio is almost certainly some significant multiple of the value captured just by the case studies and vignettes – for which \$6 billion was developed as a highly conservative estimate. The value created by recent CSIRO activities is likely therefore to be at least several tens of billions of dollars.

The fact that this current review has now found that there are robust arguments for the value of CSIRO to be “*significant multiple*” of the \$6 million amount estimated in 2010 suggests that our assumptions at the time were reasonable.

This review has included the value from significantly more case studies. However, the number of case studies is still only a very small sample of all the research projects carried out by CSIRO. There are currently around 3000 projects underway within CSIRO. ACIL Allen believes that the probability that all these other CSIRO projects would deliver no additional benefits is effectively zero.

ACIL Allen is reluctant to put a precise figure on what amount of benefits all the other research done by CSIRO might add to our estimate of \$27 billion for the net present value of the benefits from the case studies examined in this review. Nonetheless, based on our experience in conducting this kind of analysis for CSIRO we would be surprised if the outcomes of all the other research being conducted by CSIRO did not at least match the estimated \$27 billion in present value from the 28 case studies.

ACIL Allen also translated the quantitative results of the case study assessments to derive an estimated ‘average’ annual benefit. Based on the case studies where data was available to enable the R&D costs and benefits to be annualised, the estimated average total value of benefits generated per year is some \$3.2 billion.

The \$3.2 billion figure could reasonably be expected to be substantially higher if similar data for the other case studies was available. ACIL Allen believes that it is reasonable to assume that the annual value delivered by all other CSIRO research would at least match that delivered by the case studies. In that case, total annual benefits from CSIRO's research would exceed \$6 billion. This is well in excess of CSIRO's annual operating expenditure of approximately \$1.27 billion and suggests that the full CSIRO research portfolio is providing an estimated return of over 5:1.

³ Assessment of CSIRO Impact & Value, ACIL Tasman, 2010



3.1 The value of standing capacity

CSIRO's ability to access a group of researchers with a wide range of skills and expertise and quickly assemble multidisciplinary teams of researchers that can respond quickly to address difficult challenges that may emerge unexpectedly is a key source of its value to Australia. This section presents the results of a review of the recent literature and explores what the case studies and other information can tell us about this issue.

3.1.1 What does the literature review tell us?

Using multidisciplinary teams to conduct research is a key element of the majority of modern scientific research.⁴ Multidisciplinary research is often actively encouraged.⁵ For example, the Australian Government's Collaborative Research (CRN) networks program sought to encourage collaborative research as a means of increasing the research capacity of regional universities. A midterm review of the CRN program by ACIL Allen in 2015 found that it "*had been transformational for the regional universities involved. It has generated several secondary benefits such as greater internal and external networking*". It found that the CRN program had helped to improve research capacity through a range of institutional reforms, including more "*multidisciplinary approaches to research*".⁶

Multidisciplinary research is also reported to improve research outcomes. For example, Lariviere, Haustein and Boerner found that⁷

Interdisciplinary research is more successful and leads to results greater than the sum of its disciplinary parts.

The CSIRO's diverse pool of researchers, from economic geographers to cyber security specialists, allows projects to draw on the multiple specialisations already present within the

⁴ Science Europe (2014). Life, Environmental and Geo Sciences Committee Opinion Paper: Career Paths in Multidisciplinary Research. Belgium: Brussels.

⁵ Hennessy, C., and Walker, A. (2011). Promoting multi-disciplinary and inter-disciplinary ageing research in the United Kingdom. *Ageing and Society*, 31(1). Pp 52-69.

⁶ See: <https://www.education.gov.au/collaborative-research-networks-crn>

⁷ Lariviere V, Haustein S, Boerner K. (2015). *Long-Distance Interdisciplinarity Leads to Higher Scientific Impact*. *Plos One*. 10. Pp 1-15.

organisation.⁸ This potentially allows easier sharing of pooled resources, both of knowledge and infrastructure, and a reduction in lengthy procurement processes to obtain specialist advice.

This may be of particular value when a rapid response is required to a particular problem, as in the case of infectious disease outbreak. Rapid containment of, and the provision of vaccinations for, infectious diseases may have a significant positive impact on the effects of the outbreak on both local communities and the economy.⁹ This is true both of diseases that primarily affect the human population, as well as threats to other areas of important economic activity, such as agriculture.

CSIRO's response to the Hendra virus is a prime example. The virus, which affects a number of species, including humans and horses, is often fatal.¹⁰ Horse-related industries contribute over \$6.2 billion to the Australian economy every year.¹¹ CSIRO's ability to access a wide breadth of expertise was a probable contributor to the rapid development of an effective vaccine for the virus. Additionally, access to resources, such as the large-animal infrastructure at CSIRO's Australian Animal Health Laboratory, was a critical factor in making a rapid response possible. In fact, it is believed that no other institution worldwide would have had access to the specific laboratory equipment necessary to facilitate such a prompt manufacture of an appropriate cure.¹² A cost-benefit analysis in 2015 suggests that frontline investment in the vaccine that CSIRO developed had a benefit cost ratio of between 1.78 and 2.28.¹³

In addition, high levels of interdisciplinary research can help improve organisational standing and reputation; and this may help the CSIRO maintain its current research capacity. Similar national research institutions overseas have argued that, through recognition of the quality of research generated and of known capacity for multidisciplinary research, they have been more successful in attracting top researchers and project funding. An evaluation by the Research Council of Norway of the Norwegian Centre of Excellence Scheme found that:

*The combined effect of the excellence, status and the space of autonomous action provided by the long-term funding is very powerful when it comes to acquiring additional funds. (It is also) particularly successful in terms of promoting researcher recruitment and strengthening the internationalisation of...research*¹⁴

The long-term nature of key elements of CSIRO's research mandate may also aid retention of key personnel within Australia, if they are consistently funded. The Research Council of Norway found that long-term, funded research

...enables building strong research environments and attracting highly qualified scholars.^{15 16}

⁸ Commonwealth Scientific and Industrial Research Organisation, (2017). *Our research*. Available at <http://www.csiro.au/en/Research>. Accessed 08/02/2017.

⁹ World Bank, (2014). *The Economic Impact of the 2014 Ebola Epidemic: Short- and Medium-Term Estimates for West Africa*. Washington, DC: World Bank.

¹⁰ NSW Government, Department of Primary Industries (2016). *Hendra Virus – Frequently Asked Questions*. Available at <http://www.dpi.nsw.gov.au/animals-and-livestock/horses/health-and-disease/hendra-virus/faqs>. Accessed 10/10/2017.

¹¹ ACIL Allen Consulting, (2014). *Case study: Australian Animal Health Laboratory*. Available at <http://www.csiro.au/en/About/Our-impact/Reporting-our-impact/Performance-reviews/2014-impact-assessment>. Ibid.

¹³ Wilson, S. and Ward, p., (2015). *Intangible and Economic Impacts of Hendra Virus Prevention Strategies*. *Zoonoses and Public Health*, 63(5). Pp. 374-385.

¹⁴ Langfeldt, L., Brorstad Borlaug, S. and Gulbrandsen, M., (2010). *Evaluation of Added Value and Financial Aspects: The Norwegian Centre of Excellence Scheme*. Hanshaugen, Norway. The Research Council of Norway.

¹⁵ Ibid.

¹⁶ CSIRO, (2015). *The highlights, objectives and performance of our National Research Flagships*. Available at <http://www.csiro.au/en/About/Our-impact/Reporting-our-impact/Annual-reports/13-14-annual-report/Part2/Performance-portfolio/Flagships>. Accessed 07/02/2017.

This is an important source of value, and one that helps Australia to retain its capability to conduct world-class research. As mentioned above, that research may at times be highly time critical. In such cases, the CSIRO's ability to draw on its large body of expert multidisciplinary researchers to assemble a 'strike team' to quickly respond to an urgent research need is vital.

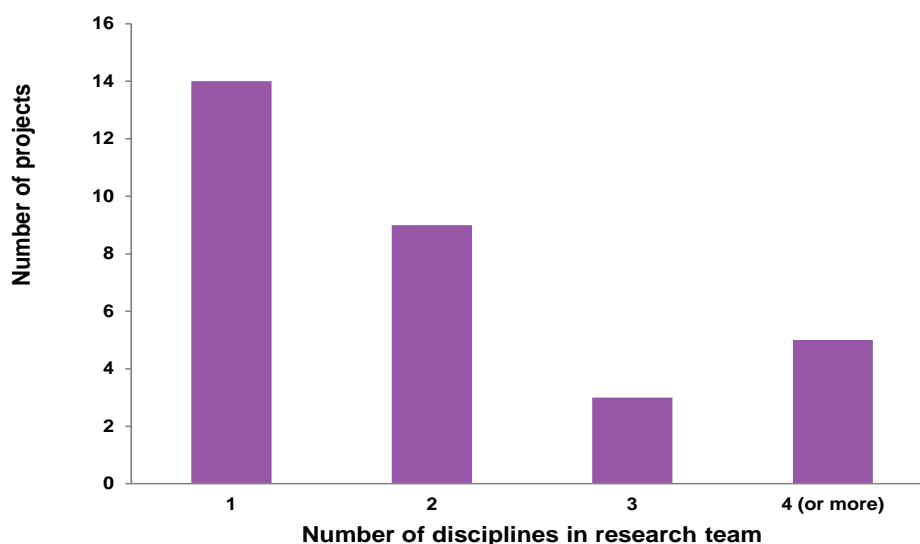
3.1.2 What do the case studies tell us?

The CSIRO has established interdisciplinary teams of researchers in order to undertake many of the case studies considered in Section 2. The number of different disciplines involved in the research teams for these case studies is shown in **Figure 3.1**. For over half of the thirty one case studies it was possible to identify research teams that had more than one research discipline.

We can also get an indication of the extent of the multidisciplinary nature of the rest of the CSIRO's research efforts. **Figure 3.2** shows the number of Divisions participating in CSIRO research teams.¹⁷ We can see that 25 per cent of CSIRO's research teams include participants from more than one Division.

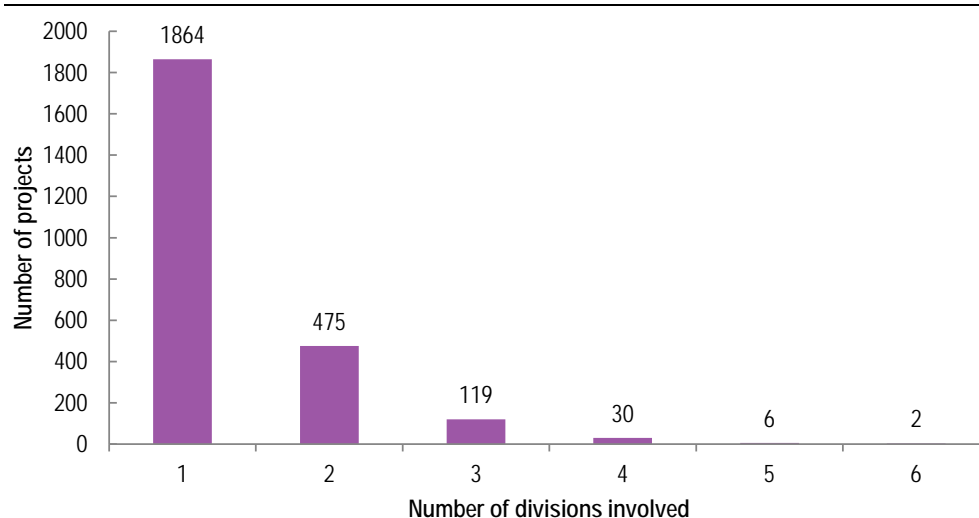
ACIL Allen is therefore highly confident in arguing that at least 25 per cent of CSIRO research teams have participants with multiple disciplines. However, this figure is highly likely to be an underestimate as it is quite possible that teams that are composed entirely of members from just one Division will still have participants with different disciplines.

FIGURE 3.1 NUMBER OF DISCIPLINES IN CASE STUDY RESEARCH TEAMS



Note: Four case studies specified that they had "many" disciplines included in their research teams. These case studies are included in the 4 (or more) category.
SOURCE: ACIL ALLEN

¹⁷ Note that the organisational structure of CSIRO was recently changed and now research activities are now grouped under Business Units rather than Divisions. However, as the data provided by CSIRO is based on the previous corporate structure the discussion in this report refers to Divisions rather than Business Units.

FIGURE 3.2 NUMBER OF DIVISIONS PARTICIPATING IN ALL CSIRO RESEARCH TEAMS

Note: There may be multiple disciplines within a single division

SOURCE: ACIL ALLEN ANALYSIS OF CSIRO DATA

There are several examples of where CSIRO has been able to use its ability to draw on researchers with a wide range of expertise in order to quickly respond to an urgent need. For example:

- Under a Memorandum of Understanding between CSIRO and the Australian Maritime Safety Authority, CSIRO provides scientific knowledge and technical support in response to maritime incidents, such as oil spills, search and rescue, and shipping accidents. In 2014, the CSIRO was called upon to assist in the search for missing Malaysian Airlines flight, MH370. CSIRO's BlueLink modelling capability was used to project the track of any debris spotted by satellites and planes during the initial search for the plane.
- In 2013 the Australian Animal Health Laboratory (AAHL) was able to quickly confirm the presence, and identify the strain, of an Avian Influenza outbreak in NSW. That information helped the NSW Department of Primary Industries to contain the outbreak and minimise its impact.
- In 2014 The World Health Organization (WHO) contacted AAHL on behalf of the Philippines Department of Health and the Research Institute of Tropical Medicine (RITM) to request assistance in the management of a deadly disease outbreak affecting both animals and people. One of AAHL's diagnostic veterinarians was deployed to Philippines. Samples were collected and sent back to AAHL where a team of diagnostic scientists were able to characterize the virus and confirm the diagnosis of the highly pathogenic Nipah virus.
- Following the Black Saturday bushfires in Victoria (which cost many lives and billions of dollars in economic losses), CSIRO was able to use its modelling capabilities to help the Victorian Government quickly assess the risks of bushfires being caused by power lines and decide how best to apply its resources to prevent similar fires in the future.
- In May 2010, researchers from the CSIRO were engaged by BP Exploration and Production Inc to help map the location and movement of an oil spill in the Gulf of Mexico. A team of scientists worked around the clock using CSIRO's hydrocarbon sensor array system to build a picture of the surface water's hydrocarbon composition. The data obtained helped BP and authorities to better understand the movement of the oil and informed important decisions, such as when fisheries should be closed.

3.1.3 Findings

There is little doubt that CSIRO's ability to respond quickly to an urgent need for scientific advice or information has value. Speed of response in the case of a disease outbreak helps to prevent the spread of the disease, save lives, and minimise economic losses. In the case of the Avian flu outbreak in NSW, a delay in diagnosis and identification of the strain could have put at risk an industry that contributes around \$1.6 billion to the NSW economy and provides 6,000 direct jobs and a further 39,000 jobs downstream.¹⁸

Similarly, the rapid provision of information to sea rescue services can mean the difference between life and death for persons involved in an incident at sea. With the statistical value of a single life being several million dollars there is a clear value attached to any lives saved.

However, the value we can confidently assign to CSIRO's standing capacity is dependent upon the circumstances. The value of a particular response can only be assessed once that response has been given. Another way of estimating value is to consider what insurance premium we might be prepared to pay to insure against a particular event. In the case of the NSW avian influenza outbreak what might be a reasonable insurance premium to pay to protect the \$1.6 billion contribution that sector makes to the NSW economy. If such outbreaks were a one in a hundred year occurrence than a premium of one per cent of the value of the industry might be justified. This would be equivalent to \$16 million a year. This figure could be regarded as a possible estimate of the value of CSIRO's standing capacity in this particular case.

ACIL Allen does not suggest that kind of calculation could or should be extended across the scope of the standing capacity services that CSIRO potentially provides. However, the calculation does provide some insight into the scale of the value delivered. CSIRO is operating in areas that make a significant contribution to the economy; it is therefore not surprising that the potential value of CSIRO's standing capacity could be considerable.

3.2 The options created by CSIRO research

CSIRO research is continually generating options for the future. Even where explicit beneficial outcomes are not yet evident, there can be value in the options created through outcomes such as enhanced capabilities, improved knowledge, better research infrastructure, clearer understanding of the most prospective areas for future research, and information on what areas of research might best be scaled back or abandoned until further information comes to hand or circumstances change.

This section presents the results of a review of the recent literature and explores what the case studies and other information can tell us about this issue. In particular, it explores the way in which CSIRO research has been used to develop and implement better informed policy.

3.2.1 What does the literature review tell us?

Scientific endeavour is a major contributor to the Australian economy. One study reported that over a quarter of Australia's economic output related to this area of activity, amounting to over \$330 billion a year.¹⁹ The study also argued that fundamental research is a key component of the innovation system, upon which applied science, a significant contributor to

¹⁸ *NSW Poultry Meat Industry Overview*, NSW Department of Primary Industries, 2015

¹⁹ Australian Academy of Science, (2016). *The importance of advanced physical, mathematical and biological sciences to the Australian economy*. Canberra, Australia.

Australia's export economy, is based.²⁰ The CSIRO is the national peak government organisation for scientific research. It produces a variety of applied and basic research outputs.

The potential benefits of applied research are often easier to both identify and quantify. Applied research often seeks to address problems that industry has already identified. The benefits tend to be innovations that lead to improved products or processes, a new breed of grain, a more efficient mechanism for improving energy efficiency of buildings, or a novel product that delivers health benefits.

It may be harder to identify the immediate benefits of fundamental research. Remedios suggests that they include new knowledge, associated social benefits and economic gain.²¹ Certainly CSIRO plays an important role in furthering the sum of human understanding through the fundamental research it conducts. For example, recently researchers at the CSIRO helped in the international effort to identify gravitational waves, the long-term implications of which are not yet identified.²² While the benefits of fundamental research may not be immediately quantifiable, there is no doubt that it can deliver value, and often quite substantial value. For example, the astronomy research done by CSIRO led to the development of the technology required for Wi-Fi. Few would argue that access to Wi-Fi has not delivered substantial social, and economic impacts.^{23 24}

However, even research that has not yet produced any identifiable benefits can deliver value. For example, by identifying areas where more (or perhaps less) research is required, the outputs of research can be used to help determine where best to assign limited resources to provide the best prospects for impact. Additionally, new methodologies and instrumentation created during the process may prove useful in other, new applications. A 2015 report by the European Commission found that:

*Many key technologies used widely in the economy have their foundations in research instruments and the relationship continues over time as the demands of leading-edge research stretch requirements and lead to solutions.*²⁵

In other areas research may lead to a better understanding of the implications of different options and lead to better informed management decisions, resulting in improved allocation of limited resources. For example, Maxwell *et al.* found that:

*Decision-makers face a trade-off between spending limited funds on direct management action, or gaining new information in an attempt to improve management performance in the future. Value-of-information analysis can help to resolve this trade-off by evaluating how much management performance could improve if new information was gained.*²⁶

National scientific institutions have a valuable role as advisors of public policy, as their remit allows for investigation of issues that are important to the national interest, but may not

²⁰ Ibid.

²¹ Remedios, C. (2013). *The Value of Fundamental Research*, International Union for Pure and Applied Biophysics.

²² Commonwealth Scientific and Industrial Research Organisation (2016). Aussie innovation helps hunt down gravitational waves. Available at <http://www.csiro.au/en/News/News-releases/2016/Aussie-innovation-helps-hunt-down-gravitational-waves>. Accessed 09/02/2017.

²³ Remedios, C. (2013). *The Value of Fundamental Research*, International Union for Pure and Applied Biophysics.

²⁴ Business for Social Responsibility, (2012). *Socioeconomic Impacts of Wireless Technology: A Review of Opportunities and Challenges in Health Care, Finance, Education and Community Empowerment*. Available at g3ict.org/download/p/fileId_920/productId_233. Accessed 07/02/2017.

²⁵ European Commission (2015). *Value of Research*. Luxembourg: Publications Office of the European Union.

²⁶ Maxwell, S., Rhodes, J., Runge, M., Possingham, H., Ng, C. and McDonald-Madden E., (2015). *How much is new information worth? Evaluating the financial benefit of resolving management uncertainty*. *Journal of Applied Ecology*, 52, pp. 12–20.

provide foreseeable economic gain.²⁷ This type of information is particularly important in areas of high complexity and uncertainty, such as the environment. In the absence of foreseeable gain it is unlikely that the private sector will invest in such research. By providing robust scientific information and presenting the results of modelling possible scenarios, CSIRO research helps inform policy decisions. The government has recognised the importance of science in informing policy decisions. A report by the then Department of Industry, Innovation, Science, Research and Tertiary Education found that:

*The Australian Public Service...is increasingly tasked with solving complex policy problems that require significant input from science in order to address them fully and appropriately*²⁸

For example, CSIRO has helped create multiple options for the management of the Murray Darling Basin, based on a range of evidence-based scenarios.²⁹ This allows for solutions to be adopted that are not only supported by robust scientific evidence, but that also take into account the social and economic implications thereof.³⁰

CSIRO is the custodian of a number of collections of animal and plant specimens that contribute to national and international biological knowledge. One of those national databases is the Atlas of Living Australia (ALA). The ALA is a database that provides free, online access to information about Australia's biodiversity. ALA supports research, environmental monitoring, conservation planning, education, and biosecurity activities. The results of a 2016 impact evaluation of the ALA are shown in **Box 3.1**.

BOX 3.1 IMPACT EVALUATION OF THE ALA

Five areas were used to assess ALA's economic, social and environmental impact and value, namely:

1. *Uptake and usage*. Has there been uptake and usage of the data delivered through ALA?
2. *Cultural change*. Has ALA influenced cultural change in the behaviours relating to open sharing of data?
3. *New products and services*. Has ALA amplified and improved the creation, delivery and competitive advantage of new products and services and enterprises?
4. *Efficiency gains*. Has ALA resulted in productivity and efficiency gains?
5. *Applications and derivatives*. To what extent has ALA helped in the application of knowledge and activities in key sectors including through the creation of "information derivatives"?

The evaluation found that ALA has delivered a range of actual and potential impacts, including reports, papers and publications and more efficient intervention and action relating to biodiversity. A cost-benefit analysis found that the annual value delivered by ALA was at least \$26.9 million and that the return on investment ratio was 3.5:1 (i.e. for every \$1 invested in the ALA at least \$3.50 economic value was created).

SOURCE: ALLUVIUM, ASSESSMENT OF THE ATLAS OF LIVING AUSTRALIA'S IMPACT AND VALUE, 2016.

The CSIRO also creates options for future research, through its investment in R&D infrastructure. Researchers overseas have sought to quantify the value of this infrastructure, in terms of possible future contributions, highlighting both social and economic benefits. For

²⁷ Ibid.

²⁸ Australian Government, Department of Industry, Innovation, Science, Research and Tertiary Education (2012). *APS200 Project: The Place of Science in Policy Development in the Public Service*. Australia: Canberra.

²⁹ ACIL Allen Consulting (2014). *CSIRO's impact and value*. Available at Available at <http://www.csiro.au/en/About/Our-impact/Reporting-our-impact/Performance-reviews/2014-impact-assessment>.

³⁰ Thwaites, T. (2014). *Research metrics: Calling Science to Account*. *Nature*, 511, pp. 57-60.

example, in relation to the Large Hadron Collider at CERN, Florio *et al.* identified four classes of direct benefits. These can be grouped under the following social groups: scientists; students and young researchers; firms in the procurement chain and other organisations; and the general public. These benefits are respectively related to the knowledge output of scientists; human capital formation; technological spillovers; and direct cultural effects for the general public.³¹

Estimates of the socio-economic value of the Large Hadron Collider at CERN were approximately €2.9 billion, with a 90% chance of the produced value exceeding investment.³²

3.2.2 What do the case studies tell us?

A number of the case studies examined in this report have a focus on providing modelling capability or research infrastructure that aims to improve our ability to manage our environment and natural resources more efficiently. For example:

- The BlueLink project – This project developed a series of models that provide accurate forecasts of ocean conditions such as waves and currents around the world. The information provided through these models is used by the Royal Australian Navy to help optimise their deployments and the fishing industry to help manage fish stocks and improve the safety and efficiency of fishing operations. The estimated net present value of the BlueLink project is \$27.2 million.
- Integrated water resource assessments – This project developed and applied a nationally consistent framework for assessing water resources and water availability under changing climatic conditions. The tools and methodologies developed provide a basis for responsible water resource management by allowing water managers to make better informed decisions about current and future trade-offs between different water uses (both for human and environmental use). The estimated net present value of this project is over \$1.2 billion.
- Synchrotron Science project – CSIRO (through the Science and Industry Endowment Fund (SIEF)) provided support for the operation of the Australian Synchrotron. In the four years between 2012 and 2016 this funding supported 243 synchrotron projects. All but thirteen were led by CSIRO. ACIL Allen has estimated that the net present value of this research was over \$715 million.

SIEF also provided a grant under its Research Infrastructure Program to support the establishment of a new Advanced Resource Characterisation Facility (ARCF) in Perth as part of the National Resource Sciences Precinct (NRSP). The ARCF provides a global hub for metre to atomic scale analyses for the research community, industry, and government geoscience agencies.

At the time that ACIL Allen reviewed the SIEF program, the ARCF equipment had only just been installed and it was too early to identify any outputs from the users' research. However, it was clear that the ARCF had been instrumental in creating a number of collaborations between research institutions and between researchers and industry. There are already a number of interesting projects underway and ACIL Allen saw clear potential for the research being undertaken to deliver very significant impact.³³

³¹ Florio, M., Forte, S., Pancotti, C., Sirtor, E. and Vignetti, S., (2016). *Exploring cost-benefit analysis of research, development and innovation infrastructures: An evaluation framework*. European Investment Bank Institute. Available at <https://arxiv.org/ftp/arxiv/papers/1603/1603.03654.pdf>.

³² Florio, M., Forte, S. and Sirtor, E. (2016). *Forecasting the Socio-Economic Impact of the Large Hadron Collider: a Cost-Benefit Analysis to 2025 and Beyond*. Available at <https://arxiv.org/pdf/1603.00886.pdf>.

³³ *SIEF Impact Review*, ACIL Allen, January 2017

3.2.3 Findings

CSIRO is a significant provider of data and modelling that both create options across a wide range of areas, and help to inform decisions between those options. It is in principle possible to use options theory to assign value to options. However the scope and breadth of CSIRO's work and the enormous range of options created makes this a task that is well outside the scope of this report.

The case study examples discussed in the previous section suggest that there is considerable value in the options that CSIRO provides. The discussion in Section 3.2.1 refers to a number of examples where evaluations have found that the benefits of the research activities being studied have conservatively been estimated to exceed their costs by a factor of two or three.

ACIL Allen finds that the estimated value delivered in this area by the case studies alone is well in excess of costs. Furthermore, on the basis of the discussion above, we would argue that it would be highly likely that the benefits of CSIRO's other activities in this area would further extend the extent to which the estimated benefits exceed the costs.

3.3 The training and education services provided by CSIRO

Education and training forms an important part of the nation's economic, intellectual and social development.³⁴ CSIRO provides considerable training and education to support the next generation of Australian researchers. The bulk of that support is provided to STEM students (see also the discussion in Section 3.4).

CSIRO's support is provided through a variety of mechanisms. It includes co-supervision of PhD students with other institutions, engaging postdoctoral students to work on particular projects and providing scholarships or fellowships to early career researchers.

This section presents the results of a review of the recent literature and explores what the case studies and other information can tell us about this issue.

3.3.1 What does the literature review tell us?

The CSIRO provides opportunities for further training and career development, through the provision of postgraduate scholarships to PhD students³⁵ and postdoctoral fellowships to recent graduates. These allow PhD students and Early Career Researchers (ECRs) access to supervision, facilities and the opportunity to work on projects of local and international significance.³⁶ A report by the Office of the Chief Scientist found that a PhD in a STEM subject can earn up to 2.7 times more than a STEM graduate with a bachelor degree.³⁷ This suggests that CSIRO's support for training and education can provide significant economic

³⁴ Australian Bureau of Statistics (2012). *Higher Education*. Available at <http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/by%20Subject/1301.0~2012~Main%20Features~Higher%20education~107>. Accessed 07/02/2017.

³⁵ Commonwealth Scientific and Industrial Research Organisation, (2016). *Postgraduate Scholarships*. Available at <http://www.csiro.au/en/Careers/Student-and-graduate-opportunities/Postgraduate-scholarships>. Accessed 07/02/2017.

³⁶ Commonwealth Scientific and Industrial Research Organisation, (2016). *Postdoctoral Fellowships*. <http://www.csiro.au/en/Careers/Student-and-graduate-opportunities/Postdoctoral-fellowships>. Accessed 07/02/2017.

³⁷ Office of the Chief Scientist (2016), *Australia's STEM Workforce: Science, Technology, Engineering and Mathematics*, Australian Government, Canberra.

benefits, as well as supporting Australia's ability to conduct the research and development that is needed to support a modern economy.

Importantly, CSIRO also provides mentoring opportunities to recent graduates. Mentoring has been shown to help both mentors and mentees, in terms of enhanced career advancement, increased productivity, improved attitudes towards the work environment, and larger numbers of grants acquired.^{38 39} For example, van der Weijden *et al.* found that those who receive mentorship:

... on average have a more positive view on their work environment and manage their research more actively (and) on average perform better in terms of acquired grants.⁴⁰

This function is particularly valuable, because although three-quarters of STEM graduates continue to work in fields directly related to their degrees, this is a lower proportion than graduates with non-STEM degrees.⁴¹ Additionally, a large proportion of these work as managers or in technical (rather than professional) positions, with 77 per cent of STEM graduates and 43 per cent of STEM PhD students working in the private sector.⁴² Evidence suggests that the reasons for STEM PhDs leaving STEM-related disciplines include lack of research opportunities and lack of permanent employment options,⁴³ potentially undermining the significant resources expended training PhD students.⁴⁴ Institutions like the CSIRO provide opportunities for STEM graduates, including PhDs, to continue to use their specialised research skills in an area directly related, or with high relevance to, their field of study.

CSIRO also has the potential to provide important opportunities for women in STEM fields. Women are underrepresented, comparative to levels of tertiary qualification, in senior positions in STEM-related research fields, and there is also a significant gender pay-gap in these arenas.⁴⁵ Women's participation in these fields has been shown to increase when a culture of inclusion is fostered.⁴⁶ Through programs such as CSIRO's 'Women in Science' initiative, the organisation can provide valuable opportunities for women to fully participate in, and contribute to, their chosen field.⁴⁷

A 2012 survey of over a thousand Australian researchers commissioned by the Department of Industry, Innovation, Science, Research, and Tertiary Education (DIISRTE) suggested a number of measures to help researchers to develop their careers. These included providing

³⁸ Straus, S., Chatur, F., and Taylor, M. (2009). *Issues in the Mentor–Mentee Relationship in Academic Medicine: A Qualitative Study*. *Academic Medicine*, 84(1), pp. 135–139.

³⁹ Ramirez, J. (2012). The Intentional Mentor: Effective Mentorship of Undergraduate Science Students, [J Undergrad Neurosci Educ](#), 11(1), pp.55–63.

⁴⁰ van der Weijden, I., Belder, R., van Arensbergen, P., and van den Besselaar, P., (2015). *How do young tenured professors benefit from a mentor? Effects on management, motivation and performance*. *Higher Education*, 69(2), pp. 275–287.

⁴¹ Australian Bureau of Statistics (2014). *Perspectives on Education and Training: Australians with qualifications in science, technology, engineering and mathematics (STEM), 2010–11*. Available at <http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/4250.0.55.005main+features72010%E2%80%9311>. Accessed 07/02/2017.

⁴² Op. cit., Australia's STEM Workforce.

⁴³ Turk-Bicakci, L., Berger, A., and Haxton, C., (2014). *The Nonacademic Careers of STEM PhD Holders*. *American Institute of Research*, 4, pp. 1–11.

⁴⁴ Department of Education and Training, (2016). *Australian Postgraduate Awards*. *Australian Government, Canberra*. Available at <https://www.education.gov.au/australian-postgraduate-awards>. Accessed 06/02/2017.

⁴⁵ Prinsley, R., Beavis, A., and Clifford-Hordacre, N., (2016). *Busting myths about women in science*. Office of the Chief Scientist Occasional Paper Series, 13, pp 1–4.

⁴⁶ Professionals Australia, (2014). *Women in STEM in Australia*. Available at http://www.professionalsaustralia.org.au/professional-women/wp-content/uploads/sites/48/2014/03/WOMEN_IN_STEM_v2.pdf. Accessed 06/02/2017.

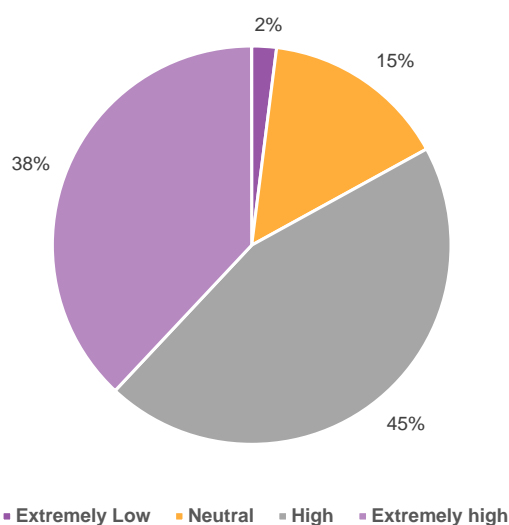
⁴⁷ Commonwealth Scientific and Industrial Research Organisation, (2016). *National Science Week 2016*. Available at <https://www.csiro.au/en/Education/Community-engagement/National-Science-Week-2016>. Accessed 02/02/2017.

support for training programs. The study found that training in generic research and non-research skills makes ECRs more employable.

ECRs that received support from CSIRO (through SIEF) were surveyed on their views about the support program. Almost half of the ECRs surveyed rated the quality of the technical training they had received as a result of the SIEF support as *extremely high* or *high*. Similarly, 78 per cent of respondents rated SIEF's support for non-technical training as either *extremely high* or *high*.

As can be seen from **Figure 3.3**, a clear majority of ECRs also rated SIEF's support in progressing their careers either *extremely high* or *high*.

FIGURE 3.3 ECRS RATING OF SIEF'S SUPPORT IN PROGRESSING CAREERS



SOURCE: SURVEY OF SIEF EARLY CAREER RESEARCHERS

3.3.2 What do the case studies tell us?

The case studies do not have much information that is of value in assessing the impact and value of the training and education that CSIRO provides. The number of PhDs or postgraduates involved in the research projects used to develop the case studies are in most cases not specified.

On a more general note, CSIRO carried out a survey of researchers who were supervising students within the organisation. Respondents were almost universally keen to supervise students. Reasons for this included:

They allow me to cover much more ground than I can on my own, and I find them very energising. I love supervising / mentoring students and postdocs.

Inspiration and enthusiasm from being around keen and talented young scientists.

Some of my students greatly contributed to some of my most cited papers.⁴⁸

Only about half the respondents identified any negatives associated with supervising students. That said, the most common negative comment, by a very wide margin, was around the lack of time they had to mentor students.

⁴⁸ Survey of early career researchers supported by SIEF.

3.3.3 Findings

CSIRO is an important partner for universities that are training PhD students. There is considerable support for providing this service among the CSIRO researchers who are co-supervising PhD students from universities across the country. It seems clear that the majority of researchers involved see considerable value in supporting the training and education of students. One of the CSIRO staff who responded to the survey of student supervisors summed it up nicely, noting that:

There are few better value options for doing research than research done via a PhD student. Engaging with PhD students represents immense value for money for CSIRO in terms of research outputs gained.

The finding that a PhD in a STEM subject can earn up to 2.7 times more than a STEM graduate with a bachelor degree suggests that there is value being delivered to the students concerned through the training and education provided to students by CSIRO. Quantifying the value is, however, difficult. ACIL Allen is aware of a number of cases where student members of research teams have joined the business CSIRO was collaborating with after completing their training. This delivers benefits not only to the student but to the firm as well.

ACIL Allen believes that there are also benefits delivered to CSIRO through these activities. As supervisors noted in their survey responses, those benefits include:

Extra work being done. More research opportunities. Broader research focus. Greater publication output. Greater linkages with universities.

Based on past experience some students have done well and contributed to knowledge in the fields we are interested (in). In my view they are useful to help do some fundamental work in areas that we have little resources, and also help increase publications.

Ability to do basic research to underpin applied research. PhD students can delve into the fundamental science more than we can with our external partners. Student research can follow up new leads which are not mature enough to be proposed to external clients. They provide the underpinning knowledge to help us inform the direction of applied research ... They also help with publication generation which in turn helps our scientific reputation which then brings in the external fee paying clients.

Finally, it is worth recognising that CSIRO PhD students or ECRs who subsequently join a private sector firm help to create pathways for commercialisation of CSIRO's research outputs.

3.4 CSIRO's support for STEM education

There is a growing concern that Australia is failing to produce sufficient graduates with STEM qualifications. CSIRO encourages students to study STEM subjects through many of its outreach activities. These include school visits by researchers and the operation of the Discovery Centre. That information could be used to estimate the potential impact on students' choice of study subjects.

This section presents the results of a review of the recent literature and explores what the case studies and other information can tell us about this issue.

3.4.1 What does the literature review tell us?

STEM education has been acknowledged as an important component in Australia's long-term security and prosperity. A recent report by the Office of the Chief Scientist summarised the importance of the STEM disciplines for Australia's future as follows:

*Australia's future will rely on science, technology, engineering and mathematics (STEM)—disciplines at the core of innovation. Our businesses will rely on STEM to compete in the emerging sectors that new technologies will create, as well as in the existing sectors which new technologies will transform. Our workforce will require specialised skills in STEM as well as high STEM literacy across the board to sustain economic growth.*⁴⁹

Supporting STEM education has a number of elements, including providing adequate education and training opportunities, upskilling specialist instructors, and increasing community engagement in science. In addition, students need to be aware of the career opportunities STEM qualifications provide and be encouraged to take an active interest in STEM subjects.

CSIRO supports, and contributes to, STEM learning in a number of ways:

- First, CSIRO outreach programs, such as the 'Scientist and Mathematicians in Schools' (SMiS) project, allow students to meet researchers directly involved in scientific endeavour. This helps alert students to possible careers in STEM areas and increase scientific literacy and interest in studying STEM subjects.⁵⁰
- Second, the program provides important professional development opportunities for teachers.⁵¹
- Third, the CSIRO Discovery Centre exposes students and the general public to science in an interactive manner.

The impact of science museums, such as the CSIRO's Discovery Centre, can also be very important. Interest in science, and scientific careers, is most often formed at an early age;^{52 53} and increasingly evidence points to much of this learning occurring outside of the traditional school environment.⁵⁴ Investment in early-years education is also suggested to have significant impact on future learning capacity.⁵⁵ Visiting science centres is reported to increase awareness of science, improve scientific literacy, change attitudes towards science, and increase interest in pursuing a science career. A report on the operation of the Questacon Science Museum in Canberra found that:

*Extracurricular science activities encouraged students to study science at school and to pursue science careers.*⁵⁶

Additionally, CSIRO provides latter-years mentoring in the form of 'Undergraduate Vacation Scholarships', which provide university students with the opportunity to collaborate with

⁴⁹ Office of the Chief Scientist (2014), *Science, Technology, Engineering and Mathematics: Australia's Future*. Australian Government, Canberra.

⁵⁰ Deakin University (2015), *Assessment of Impact and Value: Scientists and Mathematicians in Schools Program 2015*. Australia.

⁵¹ Op.cit. *STEM: Australia's Future 2014*

⁵² Maltese, A. and Tai, R. 2010, *Eyeballs in the fridge: sources of early interest in science*. *International Journal of Science Education* 32, pp. 669-685.

⁵³ Sladek, M. (1998), A report of the evaluation of the National Science Foundation's informal science education program. National Science Foundation, Washington, D.C., 40 pp.

⁵⁴ Falk, J. and Dierking, L. 2010. *The 95 percent solution*. *American Scientist*, 98, 486-493

⁵⁵ Cunha, F. and J. Heckman (2009), *The Economics and Psychology of Inequality and Human Development*, NBER working paper 14695

⁵⁶ Garnett, R. (2002), *The impact of science centers/museums on their surrounding communities: summary*. Questacon, Canberra. 14 pp.

CSIRO scientists in current projects.⁵⁷ Participation in such programs has been shown to increase student pursuit of STEM education and STEM-related careers. For example, Constan *et al.* found that:

*... participants in the [studied] outreach program... were more likely than nonparticipants to pursue an education and career in STEM.*⁵⁸

3.4.2 What do the case studies tell us?

CSIRO has used a Social Return on Investment (SROI) methodology to estimate the value of their SMiS program.⁵⁹ Generally, assessing the wider socio-economic impact of any program is a significant challenge in traditional cost-benefit analyses.^{60 61} The SROI approach integrates extra-financial benefits, such as broader intangible societal benefits, through the use of financial proxies.⁶²

The assumptions and the results of CSIRO's analysis are shown in **Box 3.2**. That analysis estimated the value of the SMiS program to be almost \$47 million.

BOX 3.2 ESTIMATING THE VALUE OF THE SMIS PROGRAM

An internal CSIRO evaluation of the SMiS program in 2015 identified three main sources of value from the program. These were quantified by considering the costs of providing similar services if the program had not existed. The per capita cost to replace the CSIRO's services were:

- Changes in student attitudes towards STEM – \$550
- Strengthened teaching of STEM subjects - \$550
- Increased understanding of community perceptions of science - \$800.

Based on these estimates, the CSIRO estimated the value of the SMiS program to be \$46.8 million.

SOURCE: CSIRO

3.4.3 Findings

The literature review suggests that CSIRO's outreach activities through the CSIRO Discovery Centre and the SMiS program are highly likely to encourage students to pursue STEM studies. Given that the Office of the Chief Scientist has identified the importance of STEM education to Australia's future prosperity, ACIL Allen believes that the CSIRO's support for STEM education is likely to be helping to deliver a desirable outcome.

⁵⁷ Commonwealth Scientific and Industrial Research Organisation (2016), Undergraduate Vacation Scholarships. Available at <http://www.csiro.au/en/Careers/Student-and-graduate-opportunities/Vacation-scholarships>, accessed 06/02/2017

⁵⁸ Constan, Z. and Spicer, J. J., (2015), Maximizing Future Potential in Physics and STEM: Evaluating a Summer Program Through a Partnership Between Science Outreach and Education Research, *Journal of Higher Education Outreach and Engagement*, Volume 19, Number 2 p. 117-136

⁵⁹ Commonwealth Scientific and Industrial Research Organisation (2014), *Social Return on Investment: Scientists and Mathematicians in Schools*. Australia.

⁶⁰ Arvidson, M., Batty, F., and Salisbury D. (2013), *The social return on investment in community befriending*, *International Journal of Public Sector*, 27:3, pp.225-240

⁶¹ Arvidson, M., Lyon, F., McKay, S. and Moro. D. (2013), *Valuing the social? The nature and controversies of measuring social return on investment (SROI)*, *Voluntary Sector Review* 4(1), pp. 3-18.

⁶² Thomas-Banke et al. (2015), Social return on investment methodology to account for value for money for public health inventions: a systematic review, *BMC Public Health*, 15:582, pp.1-14.

However, we have not been able to identify any mechanism for quantifying the value delivered as a result of that outcome.

3.5 Royalties generated by CSIRO

The commercialisation or licencing of the outputs of CSIRO's research generates royalty flows both to CSIRO and to other parties (usually businesses). This section presents the results of a review of the recent literature and explores what the case studies and other information can tell us about this issue. The focus is largely on the royalty flows to CSIRO.

What does the literature review tell us?

The benefits of research have historically been derived from both local and international licensing of Intellectual Property (IP) patents.⁶³ CSIRO has derived such income from areas as diverse as anti-influenza medication, polymer bank notes; shrimp feed, and insect repellent.⁶⁴ With patents lasting up to 25 years, royalties provide a significant long-term source of value.⁶⁵

It is very difficult to estimate the value of royalties. Negotiations between licensee and licensor as to the 'fair value' of the prospective patent can be complex, especially for early-stage research.⁶⁶ Having established a business partnership, market, social and other factors may influence what long-term profits are derived. There is seldom a linear relationship between the cost of the IP and its future value. This is in part due to the fact that the value of IP is not diminished by its use.⁶⁷ In fact, added value often results from linkages with other IP in the development of new products or procedures.⁶⁸ There is also the challenge of establishing rightful ownership, such as evidenced by CSIRO's protracted legal battle over the patents around the technology underpinning Wi-Fi.⁶⁹

Many different approaches have been developed to try to forecast the value of IP. These include approaches modelling replacement cost, profit split methodology, decision tree and Monte Carlo analyses, and estimations of average provisional benefit.⁷⁰ Of note are recent attempts to reconsider what constitutes 'fair' royalties, including the development of methodologies to calculate such values.⁷¹

Average rates of royalties for scientific IP tend to be between 4 and 6 per cent. The agreed rate will be dependent on factors such as the patent's novelty, the extent to which it improves on existing technology/processes, the potential commercial utility of the technology, and its stage of development.⁷²

⁶³ Plant variety rights are another

⁶⁴ Commonwealth Scientific and Industrial Research Organisation (2015). *Our top 10 inventions*. Available at <http://www.csiro.au/en/About/History-achievements/Top-10-inventions>, accessed 09/02/2017.

⁶⁵ Australian Government, IP Australia (2016). *Patents*. Available at <https://www.ipaustralia.gov.au/patents>. Accessed 10/02/2017.

⁶⁶ Liberman, A., Chrocziel, P., and Levine, R., eds., (2011). *Intellectual Property Valuation and Royalty Determination*. In: *International Licensing and Technology Transfer: Practice and the Law*. NY: Wolters Kluwer Law & Business, pp. 1-24.

⁶⁷ Ibid.

⁶⁸ Ibid.

⁶⁹ Australian Government, IP Australia (2016). *CSIRO's WLAN patent*. Available at <https://www.ipaustralia.gov.au/tools-resources/case-studies/csiro-wlan-patent>, accessed 08/02/2017.

⁷⁰ Anson, W. and Cawthorn, J. (2015). *Alternate approaches to the valuation of intellectual property*. Available at <http://www.ipwatchdog.com/2015/02/11/alternate-approaches-to-the-valuation-of-intellectual-property/id=54651/>. Accessed 03/02/2017.

⁷¹ Salauze, D., (2011). *A Simple Method For Calculating A "Fair" Royalty Rate*. *Les Nouvelles*, pp. 210-215.

⁷² Op. cit. Liberman et al. 2011

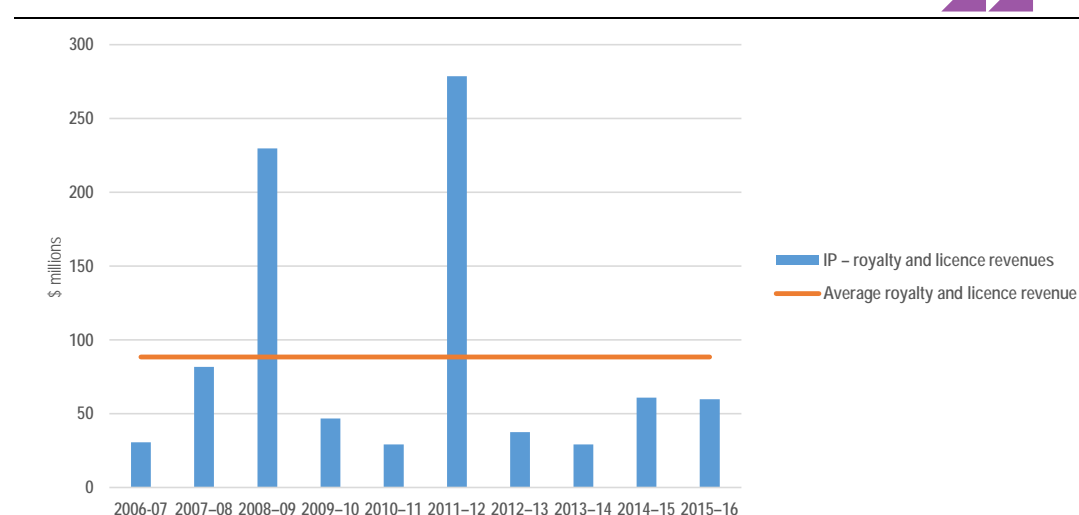
3.5.1 What do the case studies tell us?

Royalties are an important source of value provided by CSIRO. In the 2015-2016 financial year, CSIRO's licence and royalty revenues were over \$59 million.⁷³ **Figure 3.4** shows the royalty and licence fees received by CSIRO over a ten year period. The average annual amount collected was over \$88 million over the period. The average is increased due to two large payments in 2008-09 and 2011-12. These were payments of Wi-Fi royalties.

It is important to note that CSIRO does not always seek to generate revenue from their IP through licence or royalty payments. Other options include:

- Transferring the IP to the firm that is commercialising the technology and taking equity in the firm in return. In this way, CSIRO seeks to obtain a 'return on investment' through the appreciation in value of the firm commercialising the technology.
- Transferring the IP to a commercial partner without obtaining any equity or payment in return. Reasons for such an approach may include that CSIRO has judged that the contribution by the commercial partner to the development of the technology is so great that it merits such a course of action. Another reason may be a judgement that there is little likelihood that the technology would be commercialised in the absence of such an approach.

FIGURE 3.4 CSIRO LICENCE AND ROYALTY REVENUES



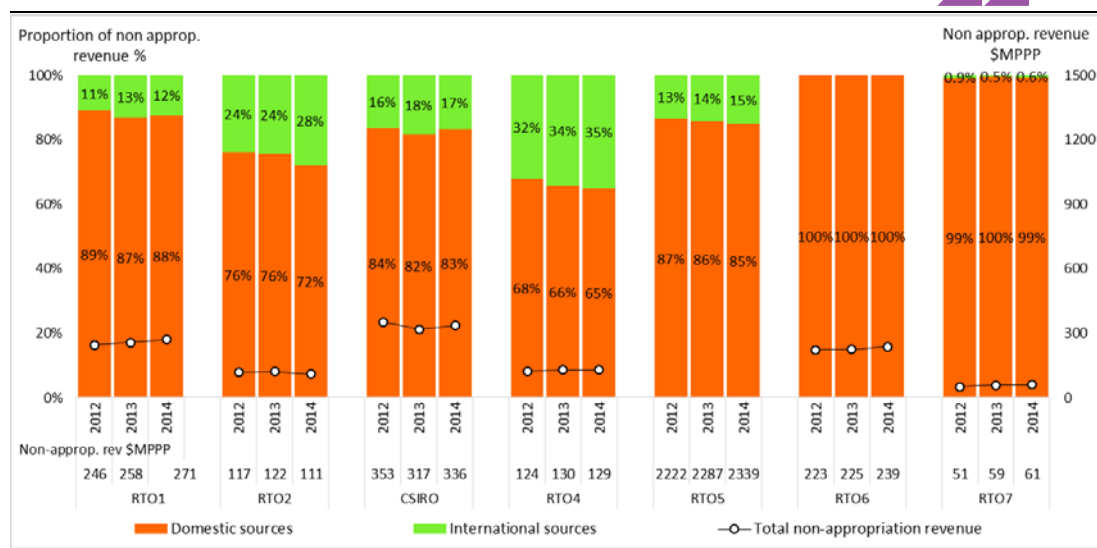
Note: The large numbers in 2008-09 and 2011-12 were due to license payments associated with the Wi-Fi technology.

SOURCE: CSIRO

In 2016, CSIRO and six other Research & Technology Organisations (RTOs) undertook a joint exercise to benchmark themselves across a wide range of key performance indicators (KPIs). **Figure 3.5** shows the non-appropriation revenues received by the seven RTOs. Non appropriation revenues would include revenues from sources such as royalties and licence fees. CSIRO has the highest amount of non-appropriation revenues of all the organisations. They also have the third highest amount of non-appropriation revenue coming from international sources.

⁷³ Commonwealth Scientific and Industrial Research Organisation (2016). *Highlights of 2015-2016*. Available at <http://www.csiro.au/en/About/Our-impact/Reporting-our-impact/Annual-reports/15-16-annual-report/Part1/Highlights>. Accessed 09/02/2017.

FIGURE 3.5 NON-APPROPRIATION REVENUES – INTERNATIONAL AND DOMESTIC



SOURCE: CSIRO

3.5.2 Findings

The money from royalties and licence fees that is paid to CSIRO obviously has value. There are a number of ways in which those funds can be used. They include bringing more resources to bear on research activities that are already underway, or using the funds to begin research projects in entirely new areas without the need to obtain additional tax payer funds.

Royalties are able to be retained by CSIRO, but may result in reduced appropriations from the government. CSIRO seeks to mitigate that risk by establishing special funds like SIEF. ACIL Allen understand that the SIEF program was established with the money from the royalty payments received for the Wi-Fi technology developed by the CSIRO. ACIL Allen’s review of the SIEF estimated the net present value (NPV) of six SIEF research projects to be \$3.5 billion in 2016-17 dollars. These are very substantial benefits. In fact, three of the projects were estimated to have returned benefits that would largely or fully offset the full amount spent by SIEF on all of its various research projects.

3.6 Collaborations engendered by CSIRO

A great deal of CSIRO’s research involves collaborations with universities, other research organisations, and/or with businesses. Some of these collaborations are entered into in order to carry out a research project; others arise over the course of the research project as challenges are identified that require additional skills to be brought into the team. Other collaborative partnerships are formed when a research project’s results emerge and pathways to commercialisation are being explored.

This section presents the results of a review of the recent literature and explores what the case studies and other information can tell us about this issue. It also reports what some of CSIRO’s business collaborators of long standing say about the CSIRO.

3.6.1 What does the literature review tell us?

Collaboration is established as an important feature of modern science.⁷⁴ The role that inter-institutional collaboration plays in enabling scientific progress is also important.⁷⁵ In an increasingly globalised world, such collaborations include partnerships with local and international scientific research organisations, universities, and private businesses. Indeed, many recent discoveries have been the result of multi-national, multi-institutional teamwork. The discovery of gravity waves (which CSIRO contributed to) is one recent example.⁷⁶

There are many benefits from collaboration. They include knowledge transfer, and the sharing of skills and techniques that may have otherwise remained highly localised. Collaborative ventures can also be a source of increased creativity, expanded networking, improved strategic leadership and management structures, and expedited capacity-building. These are all recognised as very useful outcomes.

For example Haylor *et al.* found that:

...sharing skills and knowledge, tacit knowledge sharing, learning the required social skills, and collaboration as a source of creativity were all highly valued benefits⁷⁷

Importantly, knowledge, market and network spill-overs may also occur and give rise to academic and economic gain.⁷⁸ A 2016 report by the Australian Council of Learned Academies (ACOLA) found that:

Business collaboration with research organisations on innovation increases their likelihood of productivity growth by 3 times.⁷⁹

Working together can also reduce the financial costs of research. For example, by sharing expensive research infrastructure, thereby enabling projects to proceed that may otherwise been too expensive to undertake.⁸⁰

There is evidence that international collaboration should be encouraged, as it can contribute to the completion of high-impact science.⁸¹ A study by Clarivate found that:

International collaboration boosts the citation impact of Australian research by 24 per cent.⁸²

Recent reports by the OECD support this claim, revealing that international scientific collaboration (with most partner countries) is beneficial. However, these reports also found that Australia does not rank highly in terms of participation in these kinds of team projects. While individual mobility of Australian researchers with other partner nations, such as the USA, is high, Australia's overall participation in international collaboration is less than many

⁷⁴ Science Europe (2014). Life, Environmental and Geo Sciences Committee Opinion Paper: Career Paths in Multidisciplinary Research. Belgium: Brussels.

⁷⁵ Smith, M., Weinberger, C., Bruna, E and Allesina, S. (2014). *The Scientific Impact of Nations: Journal Placement and Citation Performance*. PLOSone, 9(10), pp. 1-6.

⁷⁶ Commonwealth Scientific and Industrial Research Organisation (2016). Aussie innovation helps hunt down gravitational waves. Available at <http://www.csiro.au/en/News/News-releases/2016/Aussie-innovation-helps-hunt-down-gravitational-waves>. Accessed 09/02/2017.

⁷⁷ Haylor, G., Porter, B., Ghezae, N. and Savage, W. (2015). *Investigating Costs and Benefits of Collaborative Research*. International Foundation for Science.

⁷⁸ European Commission (2015). *Value of Research*. Luxembourg: Publications Office of the European Union.

⁷⁹ Securing Australia's Future Report number 10. *Skills and capabilities for Australian enterprise innovation*, ACOLA, June 2016, page 5.

⁸⁰ Rolin, K. (2015). *Values in Science: The case of scientific collaboration*. Philosophy of Science, 82(2), pp. 157-177.

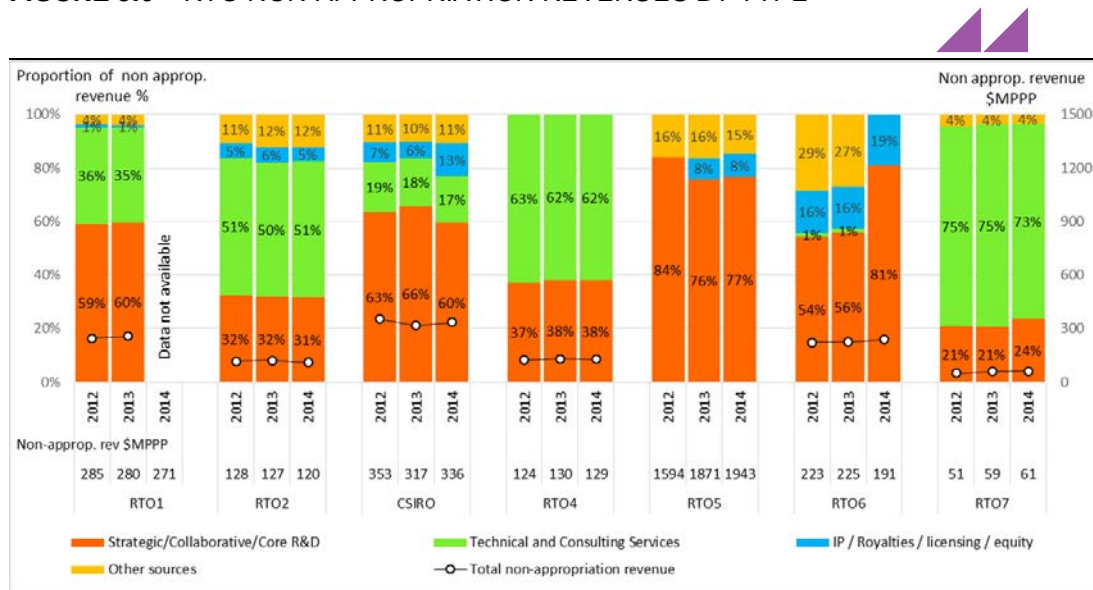
⁸¹ Op. cit. Smith et al.

⁸² Clarivate Analytics InCites™, Department of Industry, Innovation and Science analysis, December 2016.

of its European counterparts.⁸³ However, the CSIRO, with its strong international reputation and pre-established international partnerships, provides a valuable resource through which Australia can increase its participation in international endeavours.⁸⁴

In 2016, CSIRO and six other Research & Technology Organisations (RTOs) undertook a joint exercise to benchmark themselves across a wide range of key performance indicators (KPIs). **Figure 3.6** shows that CSIRO has the equal second highest average share of non-appropriation revenue associated with strategic/collaborative/core R&D activities over the period 2012-2014.

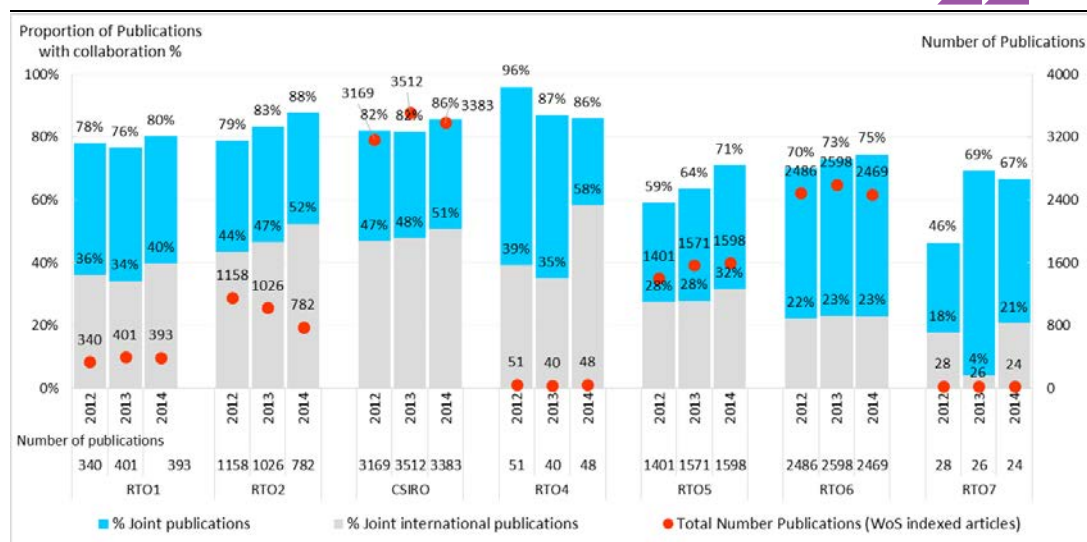
FIGURE 3.6 RTO NON-APPROPRIATION REVENUES BY TYPE



SOURCE: CSIRO

The same benchmarking project also considered the proportion of publications by the RTO with international and external collaboration. **Figure 3.7** shows that CSIRO had the highest number of publications with international and external collaborators.

⁸³ OECD, (2015). OECD Science, Technology and Industry Scorecard: Innovation for growth and society, OECD Publishing, Paris.
⁸⁴ Commonwealth Scientific and Industrial Research Organisation (2016). *International Collaboration*. Available at <http://www.csiro.au/en/About/International>. Accessed 07/02/2017.

FIGURE 3.7 PROPORTION OF PUBLICATIONS WITH INTERNATIONAL AND EXTERNAL COLLABORATION.

SOURCE: CSIRO

Another important source of value are the many public-private partnerships that CSIRO has established.⁸⁵ The CSIRO has a strong history of collaborating with private business in order to capitalise on, and make available for the public benefit, many of the technologies they developed as a result of their R&D. CSIRO's collaborations with industry have led to new products and services that range across the entire economy. For example, collaborations with industry have provided Australia with new or improved health treatments, sustainable prawn feed, improved grains for the agriculture sector, leading edge exploration and mining technology, technology to improve energy efficiency, and improved nappies.

Significantly, public-sector research also has a positive effect on productivity,⁸⁶ and there is a high rate of return on such investments. Based on a number of studies, the overall value generated by public research is between three and eight times the initial investment over the entire life cycle of the effects.⁸⁷ In addition, public investment in R&D also stimulates private R&D investment. A recent European Commission report found that:

*"[there is] clear complementarity between public sector R&D and business sector R&D, with public sector R&D influencing business R&D at the level of the economy as well as being reflected in patenting."*⁸⁸

Some academics have sought to use a 'Return on Relationship' model to measure the impacts of collaboration. This approach seeks to quantify both the number of relationships engendered, and their significance, in terms of deliverables such as publications, training events, and enhanced capabilities.⁸⁹ By maintaining, and capitalising on, existing relationships, and engendering new collaborative partnerships through novel projects, the

⁸⁵ Commonwealth Scientific and Industrial Research Organisation (2015). *Our alliance partners*. Available at <http://www.csiro.au/en/Do-business/Collaborative-research/Alliance-partners>. Accessed 05/02/2017.

⁸⁶ Bell, J., Frater, B., Butterfield, L., Cunningham, S., Dodgson, M., Fox, K., Spurling, T. and Webster, E. (2014). *The role of science, research and technology in lifting Australian productivity*. Report for the Australian Council of Learned Academies.

⁸⁷ European Commission (2015). *Value of Research*. Luxembourg: Publications Office of the European Union.

⁸⁸ Ibid.

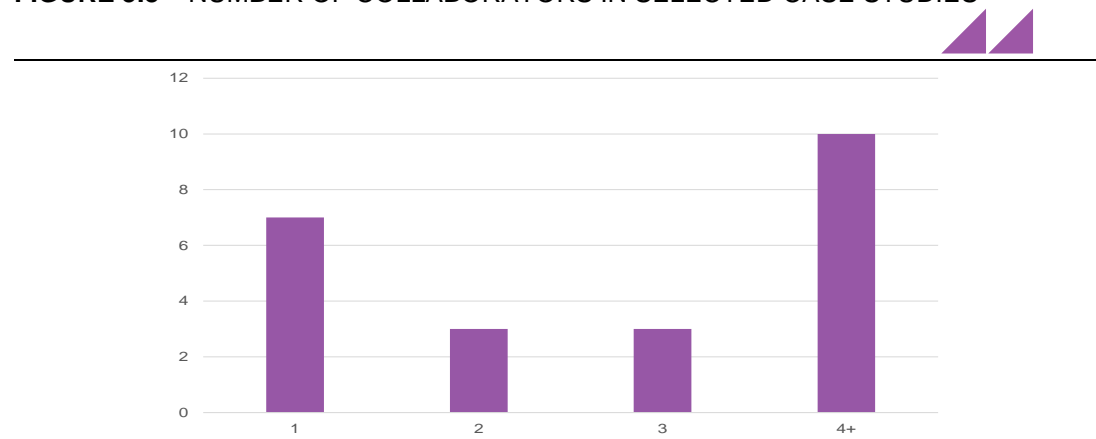
⁸⁹ Fair, J., Magnum Stokes, M., Pennington, D. and Mendenhall, I. (2016). *Scientific Collaborations: How Do We Measure the Return on Relationships?* *Frontiers in Public Health*, 4(9), pp. 1-7.

CSIRO may play a valuable role in not only supporting Australia's economic growth, but also our capacity for international scientific collaboration.

3.6.2 What do the case studies tell us?

CSIRO is clearly a highly collaborative organisation. **Figure 3.8** shows the number of collaborators for each research project for the case studies where it was possible to identify the number of collaborators. Over 43 per cent of these projects had four or more collaborators.

FIGURE 3.8 NUMBER OF COLLABORATORS IN SELECTED CASE STUDIES

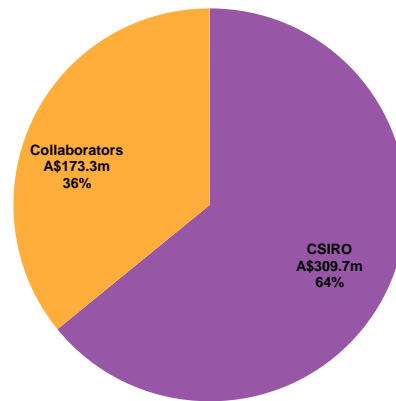


SOURCE: ACIL ALLEN CONSULTING

Collaboration is clearly important from the perspective of bringing the necessary skills and experience into the research teams. Collaboration (particularly with businesses) is also very important from the perspective of translating the outputs of research and development into commercial products and services.

Collaborators can also provide cash and in-kind support for the research being done. For the case studies where it was possible to identify the funding contributions by CSIRO and collaborators, over a third of the funding for research projects was provided by collaborators (see **Figure 3.9**).

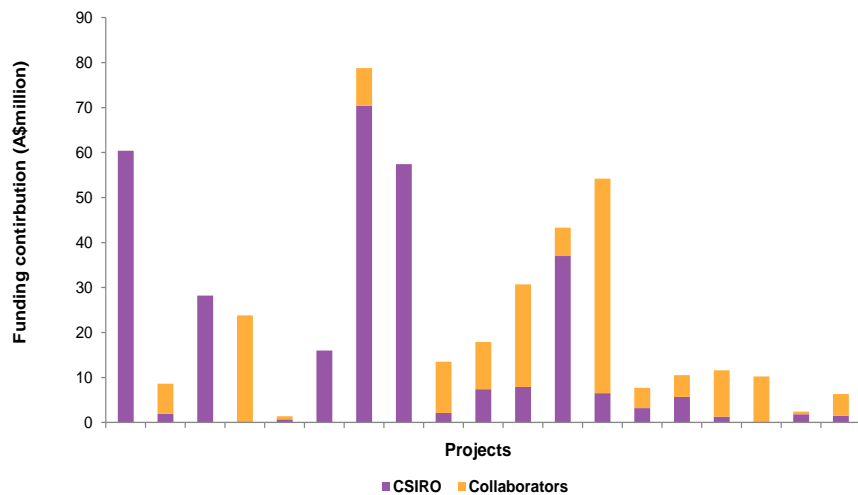
FIGURE 3.9 AMOUNT OF FUNDING FOR SELECTED RESEARCH PROJECTS



SOURCE: ACIL ALLEN CONSULTING

Figure 3.10 shows the contribution by CSIRO and collaborators by research project. We see that the proportion of funding provided by collaborators varies from zero to 100 per cent. The average share of funding provided by collaborators for all 19 projects identified was 50 per cent. However, this number was somewhat distorted by a small number of projects where funding was entirely by CSIRO.

FIGURE 3.10 CONTRIBUTIONS BY CSIRO AND COLLABORATORS BY RESEARCH PROJECT



SOURCE: ACIL ALLEN CONSULTING

If the four projects with no funding from collaborators are excluded from the calculation then the average contribution by collaborators is 63 per cent of the research project cost.

3.6.3 The views of some of CSIRO long-term collaboration partners

CSIRO has established some very long standing partnerships with industry. This has been good for the businesses in question as they have been able to draw on the skill and expertise of the CSIRO to help them commercialise CSIRO technology. One of CSIRO's collaborators stated:

The work performed was outstanding. It provided us with science and insight so that we can better make our business decisions. We are certainly happy to further collaborate with CSIRO and strongly recommend CSIRO to others.

Lihulab Energy Technology

It has also been good for CSIRO as it has helped to ensure a more rapid path to market for the outputs of its research. It has also allowed CSIRO to attract funds from the private sector in support its research (see **Figure 3.6**).

Collaboration with CSIRO has also helped businesses to continue to innovate and maintain their competitiveness. CSIRO collaborators stated:

A major benefit we have gained from investing in enabling technologies has been the ability to compete across the Asia-Pacific Region...these technologies have enhanced our production process, meaning we can produce higher quality fabrics than many of our competitors – a selling point our customers like.

Phil Butler, Director, Textor Technologies

CSIRO have been integral to MecRx developing as a company. In addition to offering flexible payment and cash investment to our company, we have also greatly benefitted from having access to scientific expertise across a range of areas close by. CSIRO have shown that they are committed to investing in innovation and industrial partnerships.

Joanne Alcindor, Founder, Director and Chief Operations Officer at MecRX

What is particularly interesting is the number of long term collaborations with business. Once collaboration is established then CSIRO often becomes a trusted long term partner. Long term collaborators with CSIRO stated:

The CSIRO team has worked with us on many thickener projects. The team is very knowledgeable and has provided guidance on very cost effective and simple to implement methods that provide significant optimisations. The team is our partner of choice in this area.

Stephane Brienne, Teck Metals Ltd.

CSIRO are one of our key research partners, and we are proud to work alongside Australia's premier industrially focused R&D entity in partnering to enhance our nation's future prospects in critical STEM areas via innovation targeting commercial prospects.

Damion Miliken, Chief Technical Officer at Dyesol Australia Pty Ltd.

CSIRO does not only collaborate with the private sector. The organisation also provides important science and technology input into public policy deliberations. Public sector collaborators commented that:

CSIRO staff endeavour to continually innovate and deliver services above and beyond our requirements. They are friendly and approachable and work in a collaborative manner to ensure our needs are met. They are considered world leaders in the field of fisheries science and can be relied upon to deliver cutting edge advice.

Viki O'Brien, Australian Fisheries Management Authority (AFMA)

„, the project is transformative. It delivers an automated state of the art forecasting capability.

RAN (speaking of the outcomes of the BlueLink project)

CSIRO is also a sought after partner in the research sector. Collaborators commented that:

CSIRO Atmospheric and Marine Science is the equal to the best in the world. This science is vital to our continued understanding of the changing climate.

Jane Mullett, Research Fellow at Royal Melbourne Institute of Technology

CSIRO staff involved in biodiversity research are absolutely stellar and have an exceptional national and international reputation. They are fantastic collaborators and are committed to excellent application of their research

Sarah Bekessy, Associate Professor at Royal Melbourne Institute of Technology

3.6.4 Findings

The evidence suggests that CSIRO is an extremely successful collaborator. Most of its projects involve collaborators, many of them multiple collaborators. Its research partners are drawn from the private, public and academic sectors. Those collaborators provide a significant source of funds in support of CSIRO's research, helping it to have the highest level of non-appropriation funding of the six RTOs it was benchmarked against.

What is particularly pleasing is that once collaboration is established it often continues over the long term, even after the original purpose of the collaboration has been addressed. CSIRO is clearly the collaborator of preference for many firms and organisations, attaining that most sought after position of 'trusted advisor'. This is exemplified by the following comment from Boeing (which has had a strategic alliance with CSIRO for 27 years):

CSIRO sets the standard with which we judge others! It's a lot more than just nuts and bolts outcomes. Together, we're creating value every day.

It is hard to assign a value to the collaborative network that CSIRO has established around Australia and across the world. The benefits from that network manifest themselves in multiple ways. For example:

- Research that is completed more quickly than would have otherwise been possible.
- Research that is broader in scope than would otherwise have been possible.
- Research outcomes that are more quickly transferred to the market than would otherwise been the case.
- A high level of trust developed between the parties which helps to drive ongoing innovation.
- Research that can be carried out at a lower cost to tax payers.

3.7 Overall findings

The discussion in this chapter has identified a large number of ways in which CSIRO adds value beyond the estimated value provided by the case studies. Our findings in each of the areas of potential value are summarised below:

- The value of standing capacity – The value of standing capacity is realised through maintaining access to researchers from multiple disciplines that can be brought together to form teams to address issues that may arise suddenly and without warning. We have shown that CSIRO has access to researchers across a wide range of areas of expertise. We have identified individual examples of rapid responses by CSIRO teams that have provided very significant value (primarily though avoided losses). We have argued that having access to standing capacity can be compared to buying insurance to protect against losses from a particular event. The amount we are prepared to pay could be regarded as an estimate of the value of CSIRO's standing capacity in this particular case. ACIL Allen does not suggest that this kind of calculation could or should be extended across the scope of the standing capacity services that CSIRO potentially provides. However, the calculation does provide some insight into the scale of the value delivered.
- The options created by CSIRO's research – CSIRO is a significant provider of data and modelling that can both create options across a wide range of areas, and help to inform decisions between those options. It is in principle possible to use options theory to assign value to options. However, the scope and breadth of CSIRO's work and the enormous range of options created makes this a task that is well outside the scope of this report. The case studies suggest that there is considerable value in the options that CSIRO provides. We identify examples where evaluations have found that the benefits of research activities have conservatively been estimated to exceed their costs by a factor of two or three. ACIL Allen concludes that the options value delivered by the case studies alone is well in excess of costs. Furthermore, on the basis of the discussion above, we would argue that it would be highly likely that the benefits of CSIRO's other activities in this area would also exceed the costs.
- The training and education services of CSIRO – ACIL Allen believes that the training and education services provided by CSIRO deliver benefits to both the trainees and CSIRO.
- Support for STEM education – The literature review suggests that CSIRO's activities through the CSIRO Discovery Centre and the SMiS program are highly likely to encourage students to pursue STEM studies. Given that the Office of the Chief Scientist has identified the importance of STEM education to Australia's future prosperity, ACIL Allen believes that the CSIRO's support for STEM education is likely to be helping to deliver a good outcome. CSIRO's own analysis estimated the value of the SMiS program to be almost \$47 million.
- Royalties and licence fees – The money from royalties and licence fees that is paid to CSIRO obviously has value. There are a number of ways in which those funds can be used. They include bringing more resources to bear on research activities that are already underway, or using the funds to begin research projects in entirely new areas without the need to obtain any additional tax payer funds.
- Collaborations engendered – The evidence suggests that CSIRO is an extremely successful collaborator. Most of its projects involve collaborators. Those collaborators provide a significant source of funds in support of CSIRO's research, helping it to have the highest level of non-appropriation funding of the six RTOs it was benchmarked against. What is particularly pleasing is that much of the collaboration continues over the long term, even after the original purpose of the collaboration has been addressed. CSIRO is clearly the collaborator of preference for many firms and organisations. It has attained the role of 'trusted advisor'. It is hard to assign a value to the collaborative network that CSIRO has established around Australia and across the world. The benefits from that network manifest themselves in multiple ways. For example:

- Research that is completed more quickly than would have otherwise been possible.
- Research that is broader in scope than would otherwise have been possible.
- Research outcomes that are more quickly transferred to the market than would otherwise have been the case.
- A high level of trust between parties which helps to drive ongoing innovation.
- Research that can be carried out at a lower cost to tax payers.

In summary, while the benefits of the areas discussed above are hard to precisely quantify, the literature reviews and the case studies support the argument that the scale of the estimated benefits from CSIRO's research is considerable.

3.8 CSIRO as a catalyst for innovation

The above discussion argues that CSIRO delivers value in a number of ways. The precise value provided by the organisation as a whole through these different mechanisms is probably almost impossible to precisely quantify. However, ACIL Allen believes that the value is likely to be considerable.

There is another way that the elements discussed above can help to contribute value, namely by helping to create an environment that fosters innovation. Indeed, some might argue that this might be the most important contributor to value,

Innovation is, of course, something that governments traditionally strive to promote. Indeed the emphasis on encouraging innovation has in recent years become an even stronger policy objective of governments. As the then President Barack Obama said in his 2011 State of the Union address:

We need to out-innovate, out-educate, and out-build the future... The first step in winning the future is encouraging American innovation.

Prime Minister Turnbull when launching the National Innovation and Science Agenda in December 2015 also stressed the importance of innovation, stating that:⁹⁰

...this package is designed to inspire. It is designed to lead. It is designed to encourage every single business, large or small to be more innovative, to be more prepared to have a go at something new because in the world of the 21st-century, in 2015, that is how you prosper.

Innovation is seen as being synonymous with showing greater flexibility, being more dynamic, more agile, more customer-focussed, and so on. And yet some of the best innovations often occur by accident, or as the result an unexpected encounter. Christian Busch, Associate Director of the Innovation and Co-Creation Lab at the London School of Economics' (LSE), states:

The core assumption in this rapidly changing world is that we often don't really know which questions to ask or which people or resources we might need to tackle the complex problems that are always evolving.

He cites drug discovery as an example, noting that drugs from penicillin to Viagra were discovered by accident – not because somebody was actively looking for them.⁹¹ He argues that because the researchers were very good at setting up these experiments and getting

⁹⁰ <https://www.pm.gov.au/media/2015-12-07/launch-national-innovation-and-science-agenda> accessed 9 March 2017

⁹¹ Thomas A. Ban, *The role of serendipity in drug discovery*, Dialogues Clin Neurosci. 2006 Sep; 8(3): 335–344.

the right procedures and teams in place, they made it more probable that these 'serendipitous' discoveries would occur.

Professor Ian Frazer recently gave an interview that reinforced the serendipitous nature of discovery. Professor Frazer who was responsible for the vaccine that protects against human papillomavirus and therefore cervical cancer still considers his discovery from 10 years ago as lucky. Speaking at the World Science Festival in Brisbane, co-inventor of the vaccine Ian Frazer said:

I just happened to be in the right lab in Melbourne, with the right people around me and the right prompt, That's the other thing about science, it's a lot of hard work but ... also, you have to have luck.⁹²

Wi-Fi is a well-known example of a serendipitous discovery made by CSIRO. The research that led to the development of Wi-Fi technology was being pursued for completely different reasons; and it was only later that its potential use in Wi-Fi became evident. The Energy Waste case study provides another example of a discovery which may be commercialised in a way completely different from what was initially thought when the project began. What was originally begun as a project to develop a technology for capturing CO₂ produced outputs that are now being developed for use as a potential anti-corrosion coating.

ACIL Allen is aware of many examples where CSIRO has worked with firms to help them to implement new and innovative technology. The case studies provide a number of examples of such firms. This ongoing and collaborative relationship is often the key to the successful translation of new technology into new products and services.

So what kinds of things can be done to create an organisational culture where serendipitous discovery and innovation is more likely to occur? Christian Busch provided an example:⁹³

...a couple of guys at NESTA have tried out a 'randomised coffee trial', where they have people randomly meet – creating an encounter that they wouldn't usually have, and talk about things they would not usually talk about. This is a simple mechanism which enables people to have more serendipitous encounters.

The discussion below considers how some of the elements of value discussed above could be contributing to an organisational culture and work environment (atmosphere) that enables and encourages people to develop new ideas.

CSIRO's standing capacity

The ability to assemble multidisciplinary teams from the one organisation should help enable faster results from research. ACIL Allen argues above that multidisciplinary teams are also likely to lead to more successful outcomes from research. One might argue that it is the opportunity to have those 'encounters' between researchers from different parts of the organisation that helps to generate new ideas and approaches to address research challenges and to identify unexpected uses for any discoveries that are made.

The options that CSIRO creates

As we noted above, CSIRO plays an important role in furthering the sum of human understanding through its fundamental research. The options created are a potential source for serendipitous discoveries. The work done by CSIRO to support the discovery of gravity waves provides an example of how work done to support fundamental research can deliver

⁹² <http://mobile.abc.net.au/news/2017-03-25/ian-frazer-recalls-lucky-discovery-of-cervical-cancer-vaccine/8385872> accessed 29 March 2017.

⁹³ <http://www.nesta.org.uk/>

many benefits, such as collaborative partnerships, an enhanced reputation, and international recognition.

It is still too early to judge what the potential commercial outcomes of the LIGO research supported by CSIRO might be. However, CSIRO has now developed a leading edge optics polishing and coatings capability as a result of its research and development and this is likely to create options for new areas of research.

ACIL Allen also recently learnt of a chance encounter between a CSIRO research team and a manufacturer of high tech equipment which has led to a decision to jointly examine the feasibility of commercialising a technology developed by CSIRO. Again, we understand that the potential commercial use of the technology in this particular way was not something that was initially being considered by the researchers.

Training and education

CSIRO's support for training and educating the next generation of researchers would contribute to an atmosphere of collegiality and trust within CSIRO. This is an atmosphere that is conducive to staff feeling free to discuss and advance new approaches and ideas.

CSIRO's collaborative approach

The high degree of collaboration (particularly interdisciplinary collaboration) that is evident in CSIRO research activities serves to enhance the opportunity for the kinds of meetings and conversations to occur that would increase the likelihood of a serendipitous discovery.

What supporting evidence is there of CSIRO's capacity for innovation? In 2016, Reuters News and Clarivate Analytics combined to present the report entitled *Top 25 Global Innovators: Government*. The report identified the government agencies, who by virtue of their published research as well as their demonstrated success in claiming and defending their intellectual property in the form of patents, were ranked among the top 25 such organisations in terms of their innovation. The only Australian organisation to make the list in 2016 was CSIRO, which ranked number 20.

The most recent edition of the same publication was issued in March 2017. Again, CSIRO was the only Australian government agency to make the list of the top 25 government agency innovators, this time ranking at number 18. The fact that CSIRO is ranked among the top 25 innovators among government research agencies globally is a considerable achievement for the organisation and a positive sign that CSIRO is recognised as an internationally important catalyst for innovation.



4.1 Conclusions

A re-examination of previous case studies has found that the estimated present value of benefits from the 28 case studies (where benefits data is available) is approximately \$27.3 billion in 2016/17 dollars (based on a 7 per cent real discount rate). This is almost twice the total funding provided to CSIRO by the Australian Government since 1978-79.

ACIL Allen also used the case study assessments to develop an estimated 'average' annual benefit. Based on the case studies where data was available to enable the R&D costs and benefits to be annualised, the estimated average total value of annual benefits is some \$3.2 billion. However, the case studies only consider a small subset of the total research conducted by CSIRO. ACIL Allen believes that it is reasonable to assume that the annual value delivered by all other CSIRO research would at least match that delivered by the case studies. In that case, total annual benefits from CSIRO's research would exceed \$6 billion. This suggests that the full CSIRO research portfolio is providing an estimated return of over 5:1.

As with any project that seeks to estimate the impact and value based on assumptions about the future, the results are subject to a degree of uncertainty. Changes to the assumptions can make a big difference (either up or down) to the estimated benefits. ACIL Allen has sought to recognise this fact by striving to adopt assumptions that are robust, yet conservative. We have also argued that the relatively small number of case studies compared to the total number of research projects that CSIRO conducts provides confidence that the estimated benefits delivered by the case studies provide a reasonable figure for the lower bound of the value of CSIRO.

A review of the assumptions used in three previous case studies demonstrated that some of our past assumptions were incorrect. However, it also found that the assumptions were as likely to have been too conservative as they were to be overly optimistic. For the three case studies that we re-examined in this report we concluded that the net result was that any change in the estimated benefits of the case studies was unlikely to be significant.

We have also examined six other ways in which CSIRO could deliver value. We conclude that, while it is generally difficult to quantify the potential benefits delivered by these six other pathways to value, it is reasonable to argue that they have the potential to deliver considerable additional value.

ACIL Allen has identified what we believe is a robust and reasonable estimate of the lower bound for the value of CSIRO's research. However, there are several reasons why the value delivered by CSIRO could be considerably more than that amount, including:

- The fact that only 28 out of several thousand projects have been developed as case studies. The chance that none of the other research projects would deliver any benefits at all is minimal.
- The qualitative analysis of the six other pathways by which CSIRO might deliver benefit suggests that the potential value they might deliver is considerable.

We also considered how CSIRO's structure and operations help to create a culture within the organisation that enhances the chance that serendipitous discoveries will be made and innovation will occur. This ability to catalyse innovation is perhaps the greatest source of the value that Australia derives from the CSIRO.

4.2 Alignment with Australia's National Science Statement

On 22 March the Minister for Industry, Innovation and Science released the Government's National Science Statement. The Science Statement articulates the government's vision and objectives for Australian science, and sets principles for government policy-making in science. The Statement sets out a vision and strategic policy framework for science in Australia; and establishes whole of Government principles that are intended to guide decision making and provide a secure, stable and enduring foundation for Australian science. It sets out the government's enduring science objectives and principles and provide guidance for the government's other science-related policies and initiatives in the future. The Government's vision is:

...for an Australian society engaged in and enriched by science

The Statement goes on to specify four objectives that need to be achieved to deliver that Vision, namely:

1. Engaging all Australians with science
2. Building our scientific capability and skills
3. Producing new research, knowledge and technologies
4. Improving and enriching Australians' lives through science and research.

The analysis of the case studies and the discussion of other sources of value contained in this report demonstrate that CSIRO is helping to achieve all four of these objectives. This is discussed below.

Engaging all Australians with science

CSIRO helps to engage Australian's with science in a number of ways, including:

- Outreach programs, such as the 'Scientist and Mathematicians in Schools' (SMiS) project, which allows students to meet researchers directly involved in scientific endeavour. This helps increase scientific literacy and interest in studying STEM subjects.
- SMiS also provides important professional development opportunities for teachers.
- Through the CSIRO Discovery Centre which exposes students and the general public to science in an interactive manner.
- Through the information about the CSIRO's R&D issued by public relations and marketing arm of the CSIRO.

Building our scientific capability and skills

Several of the CSIRO case studies examined in this report have specifically invested in either creating new research infrastructure or facilitating access to existing research infrastructure. The ARCF and the Synchrotron case studies provide two good examples of such projects. Florio *et al.* identified four classes of direct benefits in relation to the Large Hadron Collider at CERN. These benefits related to the knowledge output of scientists; human capital formation; technological spillovers; and direct cultural effects for the general public.⁹⁴

In addition to indirect mechanism such as research infrastructure, CSIRO also increases Australia's capabilities and skills through direct measures such as the training and education it provides to support the next generation of Australian researchers.

Producing new research, knowledge, and technologies

Almost all of the CSIRO case studies examined in this report have delivered new research that has increased knowledge and led to the development of new technologies.

Improving and enriching Australians' lives through science and research

Many of the case studies we have discussed in this report have produced outputs that have already helped, or are expected to help, improve the lives of Australians. The research done has delivered outputs that are expected to improve the health of the population, improve the sustainability of the economy and increase the opportunities for employment.

4.3 Some final observations

There was no specific requirement in the scope of work for this project to provide recommendations. However, over the course of this project we identified a number of ways to improve how reviews such as this one are conducted in future. These included:

- Ensuring that all future case studies are prepared in a consistent manner and adopt the same methodology so that their findings can be compared to, and combined with, those of previous case studies.
- Providing support for future evaluations of CSIRO by:
 - Systematically recording instances where CSIRO assistance or advice is urgently sought - in particular by governments.
 - Tracking the number of PhD students and postdoctoral students supported by CSIRO over time.
 - Surveying PhD students and early career researchers (ECRs) to seek their views on the support provided by CSIRO and its impact on their careers.
 - Surveying visitors to the CSIRO Discovery Centre.
 - Continuing to benchmark itself against other international research and technology organisations.
- Establishing a program to review the assumptions made for case studies to assess whether they remain reasonable. Such reviews could reasonably be done after an elapsed period of around five years.

⁹⁴ Florio, M., Forte, S., Pancotti, C., Sirtor, E. and Vignetti, S., (2016). *Exploring cost-benefit analysis of research, development and innovation infrastructures: An evaluation framework*. European Investment Bank Institute. Available at <https://arxiv.org/ftp/arxiv/papers/1603/1603.03654.pdf>.