

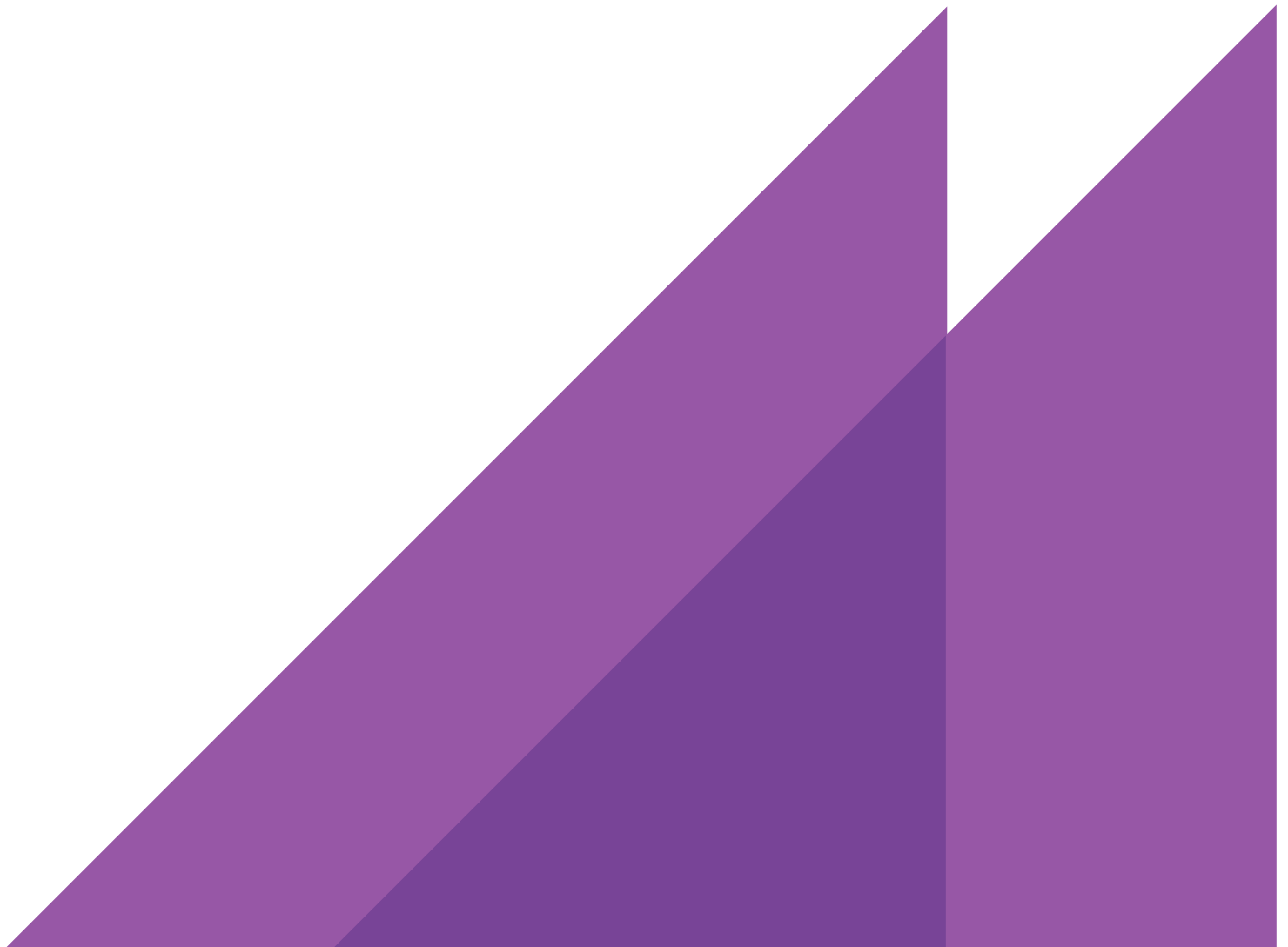
REPORT TO
CSIRO

NOVEMBER 2018

THE IMPACT AND VALUE OF CSIRO RESEARCH



2018 UPDATE REPORT
FINAL





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EXECUTIVE SUMMARY

CSIRO commissioned ACIL Allen Consulting (ACIL Allen) to prepare this update to its 2017 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 VALUE OF CSIRO - 2018 UPDATE REPORT

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

- The estimated present value of benefits across the 21 case studies where it was possible to estimate annualised benefits data is approximately \$1.27 billion per year (in 2017/18 dollars), based on a 7 per cent real discount rate.
 - the estimated annual benefit of just these twenty-one new projects comfortably exceeds the annual funding provided by the Commonwealth (\$793.5 million) and almost matches the total budget of the CSIRO (\$1,292.7 million).
- The case studies in this update report are a small subset of the total research conducted by CSIRO. ACIL Allen argues 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. This would suggest that the total annual benefits from CSIRO's research would be around \$2.6 billion. This suggests that the full CSIRO research portfolio is providing an estimated return of around 2:1.
 - the fact that each report on the impact and value of CSIRO has identified additional benefits strongly supports that argument and a finding that the same argument applies equally to this current review
 - in 2017 the estimated return was around 5:1. However, the lower ratio generated by the case studies in this update report is not surprising given the uncertain nature of research. It is highly probable that similar reviews in future will sometimes identify outcomes and impacts that generate higher ratios and at other times the ratio might be lower.
- The report discusses several other ways in which CSIRO provides value. This provides further confidence that the actual value delivered by CSIRO is likely to be considerably higher than the estimate based on the results of the case studies alone.
 - for example, many of CSIRO's projects help to enhance public trust and support organisations' and firms' social licence to operate, which is crucially important to industries that are a major component of our economy and significant employers.

SOURCE: ACIL ALLEN

As shown in **Box ES 1**, the value delivered by CSIRO is considerable. However, ACIL Allen would argue that it is entirely reasonable to expect that the impact and value of successful research outputs will be considerable since CSIRO conducts leading edge research into very many of the important issues that our economy and society currently face.



In the second half of 2016 CSIRO commissioned ACIL Allen Consulting (ACIL Allen) to carry out a study to estimate the impact and value that CSIRO delivered to the economy and the innovation system as a result the public funding it receives.¹ This report provides an update of the analysis conducted for that study.

1.1 How do we measure impact and value?

ACIL Allen has adopted a case study approach to estimate the impact and value of CSIRO. This is like the approach used in the 2017 Value Report.² For this report we examined the 33 case studies that had been completed since the 2017 report. The case studies were a mix of ones prepared by ACIL Allen and other consultants and internal ones by CSIRO. Our analysis of case studies allowed us to develop a robust and defensible lower bound estimate of the value that CSIRO's research has delivered.

Selecting a limited number of projects to develop as case studies will inevitably lead to a discussion of the representativeness of those activities and the extent to which the selection might lead to bias. It is undoubtedly important to avoid (implicit or explicit) extrapolation from a few success stories to an aggregate value estimate. However, it is also important to avoid the reverse bias of assuming that investments that have not (yet) delivered large and explicit benefits have been a waste of money. Investment in R&D, and innovation more generally, is inherently risky. The outcomes of research are inherently uncertain. If this was not the case, then there would be little need for publicly funded R&D.

Of course, even where explicit beneficial outcomes are not yet evident, there can be value in the options created through research outcomes such as enhanced capabilities, improved knowledge, better research infrastructure, and clearer understanding of the most prospective areas for future research.

The alternative approach of seeking to estimate the benefits that flow from every CSIRO research project would require so much time and resources that it would be impractical. ACIL Allen would argue that our estimates of the impact and value delivered by the research projects selected as case studies are not only robust, but also highly conservative; and that they hence provide a highly defensible lower bound to the value delivered by CSIRO. A lower bound, which is much more likely to be an underestimate, rather than an overestimate, of this value.

ACIL Allen has also mapped 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 CSIRO as a whole; and to identify which case studies provided supporting evidence for the potential value delivered through other pathways.

¹ The Value of CSIRO – An Estimate of the Impact and Value of CSIRO's Portfolio of Activities, May 2017

² Ibid.

1.2 The 2017 Value Report

The 2017 report examined 28 past case studies conducted by ACIL Allen and others. The results were used to develop a conservative and robust 'base line' estimate of the value delivered by CSIRO. The report was completed in May 2017. The key findings are summarised in **Box 1.1**.

BOX 1.1 FINDINGS OF THE 2017 VALUE REPORT

ACIL Allen's 2017 estimate of the impact and value of CSIRO found that:

- The estimated present value of benefits across the 28 case studies where benefits data was available was approximately \$3.2 billion per year (2016/17 dollars, based on a 7 per cent real discount rate).
 - This was 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 were only a small subset of the total research done by CSIRO. ACIL Allen concluded that it was reasonable to assume that the annual value delivered by all other CSIRO research would at least match that delivered by the 28 case studies examined. If so, this would mean that the total annual benefits from CSIRO's research would exceed \$6 billion.
 - This suggested that the full CSIRO research portfolio provides an estimated return of over 5:1.

SOURCE: ACIL ALLEN'S 2017 REPORT ON THE VALUE OF CSIRO

1.3 The 2018 Update Report

CSIRO has commissioned ACIL Allen to prepare an update to the 2017 report. It is a stand-alone document that could be viewed as an 'interim report' that updates the reader on some of the impacts that CSIRO has delivered since the 2017 report was issued. The intention is that the report would provide a quotable source of information that could fill what might otherwise be a relatively long gap between the 2017 report and the planned 2019 report.

The Update Report focusses on the 33 case studies have been completed since the 2017 report was completed. **Table 1.1** lists the case studies considered for the 2018 report. It also shows the author of the case studies and whether a cost benefit analysis (CBA) was done.

TABLE 1.1 CASE STUDIES EXAMINED IN THIS REPORT

Case Study Name	Author of Case Study	Cost Benefit Analysis done?
Advanced Resource Characterisation Facility (ARCF)	ACIL Allen	No
Australian e-Health Research Centre	CIE	Yes (partial)
Biomarkers for detection of colorectal cancer	CSIRO	Yes
Biosensors for Health and Food: Cybertongue / Cybernose	CSIRO	Yes
Boron Molecular	ACIL Allen	Yes
Clinical Terminology Tools	CSIRO	Yes (partial)
Concentrating Solar Power	ACIL Allen	Yes
Direct Injection Carbon Engine	CSIRO	Yes (partial)
Distal Footprints	ACIL Allen	Yes
Dry Slag Granulation	CSIRO	Yes
Foot and Mouth Disease	CSIRO	No
Future Grid Forum & Electricity Network Transformation Roadmap	CSIRO	Yes

Case Study Name	Author of Case Study	Cost Benefit Analysis done?
GISERA - Agricultural Land Management	ACIL Allen	Yes
GISERA - Aquifer Managed Recharge	ACIL Allen	No
GISERA – Community well being	ACIL Allen	No
High Pressure Processing (HPP)	CSIRO	Yes
Impromy	CIE	No
Iron Ore Sintering	CSIRO	Yes
Lab-at-rig	ACIL Allen	Yes
Laser Interferometer Gravitational-Wave Observatory (LIGO)	ACIL Allen	No
MR Ore Sorter	CSIRO	Yes
Northern Australia	ACIL Allen	Yes
Oventus Medical	ACIL Allen	Yes
Patient Admission Prediction Tool	CSIRO	No
Protein Production Facility	ACIL Allen	Yes (partial)
Rabbit Biocontrol	CSIRO	Yes
Reflexivity	ACIL Allen	Yes
Reservoir Rejuvenation Technology	CSIRO	Yes
Textor	CSIRO	No
Total Wellbeing Diet Online	CIE	Yes
Care Assessment Platform / MoTER cardiac rehabilitation program	CIE	Yes
Vaximiser	CIE	Yes
Weed Biocontrol	CSIRO	Yes

Source: ACIL Allen

As can be seen from **Table 1.1**, it was not possible to prepare a CBA for every case study. Reasons for this included: that information on benefits were regarded as commercial in confidence (for example, the Textor project); that it was too early to be able to confidently attribute any benefits (for example, the ARCF project), or that it was not possible to confidently quantify the benefits (for example, the GISERA - Aquifer Managed Recharge project).

We would emphasise that an inability to provide a cost benefit analysis for any particular project should not be interpreted as suggesting that it has not delivered benefits. For example, the Advanced Resource Characterisation Facility project in Perth provides researchers with access to highly advanced equipment for use in minerals research. It provides a global hub for metre to atomic scale analyses within the National Resource Sciences Precinct.

The success of ARCF has helped drive the adoption of an MOU between CSIRO and all five of the universities in WA. This has led to a much more coordinated approach to the acquisition and use of capital equipment. While it is still too early to judge the impact and value of the research infrastructure provided by the ARCF, the high levels of utilisation and the increasing interest in the capabilities of the equipment from the private sector suggest that it is only a matter of time before significant benefits begin to flow.

Similarly, CSIRO's contribution to the LIGO project was an internationally recognised contribution to the ground-breaking discovery of gravitational waves. This has provided a significant boost to CSIRO's reputation for scientific excellence in the field of optical fabrication, coating and metrology and helped to attract significant international research funding. The fact that the 2017 Nobel Prize for

physics has since been awarded to three of the researchers involved in the discovery of gravity waves will only add to CSIRO's reputation.

The structure of the remainder of this report

Chapter 2 maps the 'new' case studies against various criteria, including:

- their distribution across the economy
- the government's science priorities
- innovation outcomes.

Chapter 2 also reviews the consolidated CBA results for all case studies and compares the total return on investment to the result in 2017 value report.

Chapter 3 discusses any follow up actions identified during this study. In particular, the report considers what progress has been made in implementing any of the recommendations made in the 2017 Value Report. This chapter also provides a brief description of a joint CSIRO - ACIL Allen project that seeks to develop a framework for evaluating the impact that CSIRO-funded research has on public policy.

Appendix A provides a short summary of each of the case studies considered for this report.



This section that discusses the new case studies and compares them to the case studies in the 2017 Value report. The section examines the case studies against the following criteria:

- Their distribution across the economy
- Their alignment against the government's National Science and Research Priorities
- The innovation outcomes that they have delivered.

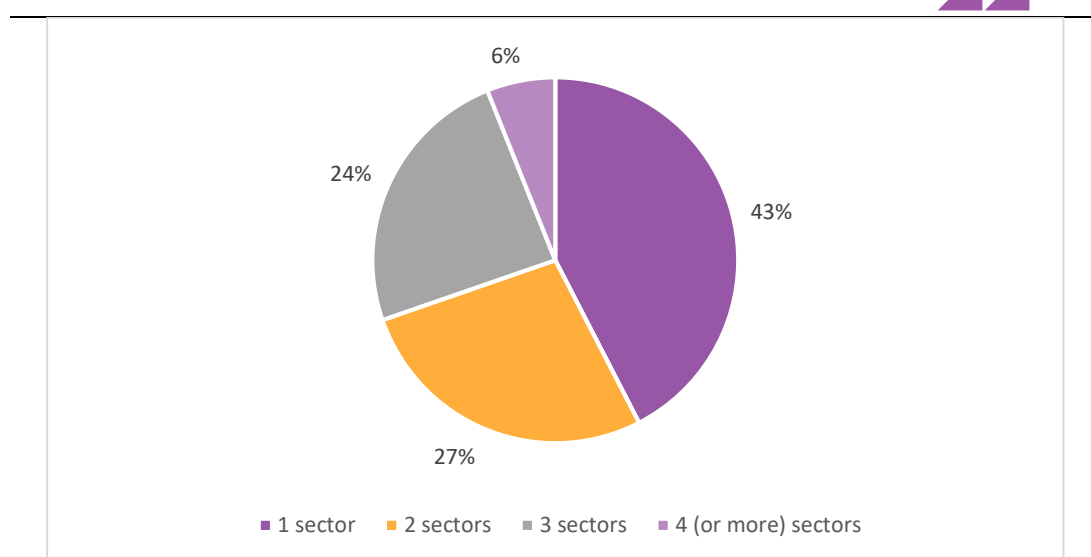
2.1 Distribution across the economy

The case studies illustrate that CSIRO's research covers a broad cross section of the economy. ACIL Allen has found that the case studies range across 15 sectors of the economy.

The sectors covered by the case studies include mining/fuel resources, manufacturing, agriculture, meat and dairy, health, pharmaceuticals, defence and security, transport, infrastructure, energy, environment, waste management, art, entertainment and fundamental research.

All the projects examined affect at least one sector, and some research projects affect up to six sectors of the economy. The proportion of case studies that impact one, two, three and four or more sectors of the economy is shown in **Figure 2.1**. The data shows that about 65 percent of the case studies impact two or more sectors of the economy.

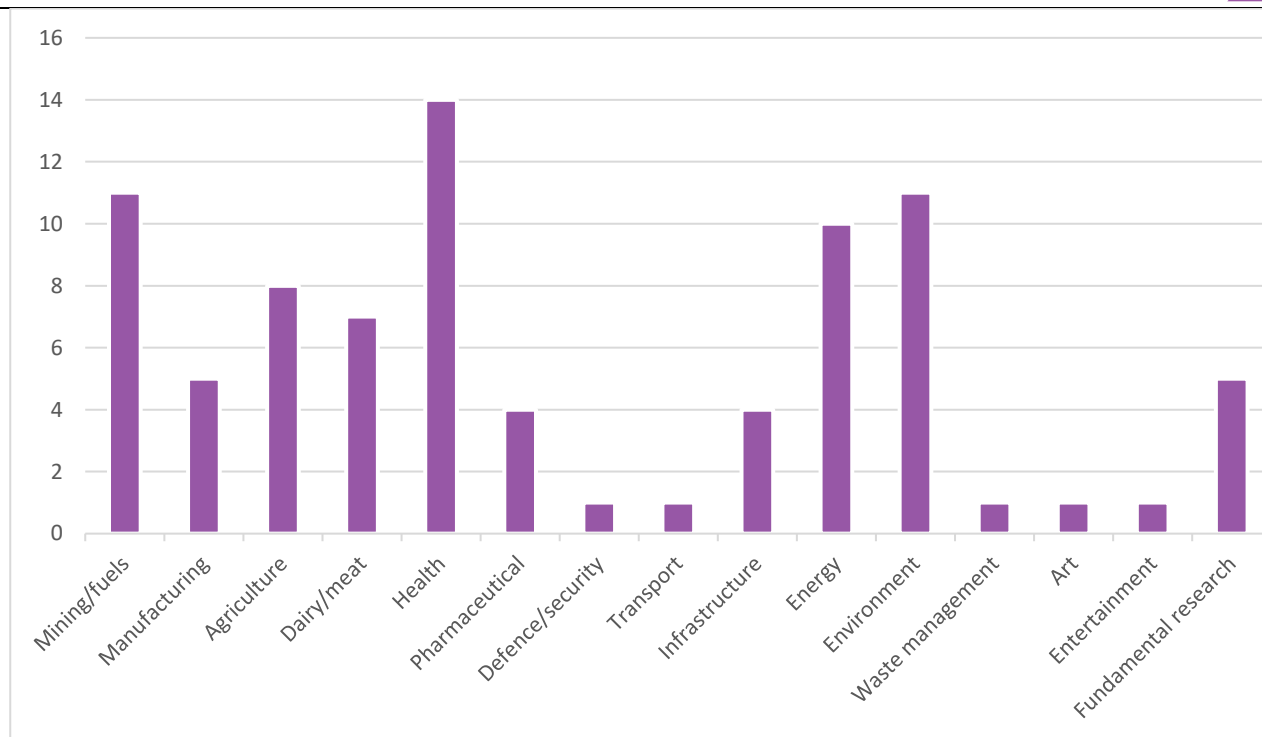
FIGURE 2.1 NUMBER OF SECTORS AFFECTED BY CASE STUDIES



SOURCE: ACIL ALLEN

The spread of research projects influencing different sectors of the economy is illustrated in **Figure 2.2**. The 33 studies considered in this report ranged across 15 sectors of the economy. Ten of the sectors listed in **Figure 2.2** had four or more projects seeking to address different challenges for that particular sector.

FIGURE 2.2 NUMBER OF PROJECTS ACROSS DIFFERENT SECTORS OF THE ECONOMY



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SOURCE: ACIL ALLEN

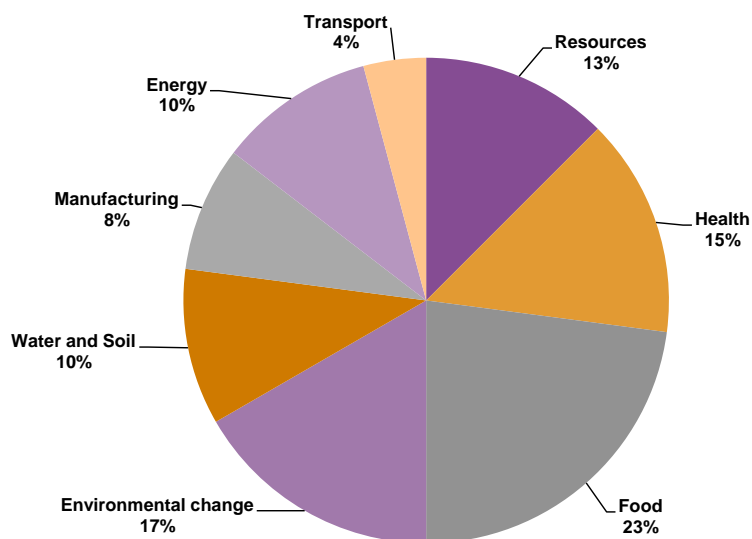
2.2 Mapping against the government's science priorities

The government has identified nine National Science and Research Priorities, namely:

- Food
- Soil and water
- Transport
- Cybersecurity
- Energy
- Resources
- Advanced manufacturing
- Environmental change
- Health

Figure 2.3 shows how the case studies for the 2017 report aligned with the National Science and Research Priorities. As might be expected, all case studies align with one or more of the priorities. Two case studies aligned with two priorities and two aligned with three or more priorities.

FIGURE 2.3 ALIGNMENT OF THE 2017 CASE STUDIES WITH NATIONAL SCIENCE & RESEARCH PRIORITIES



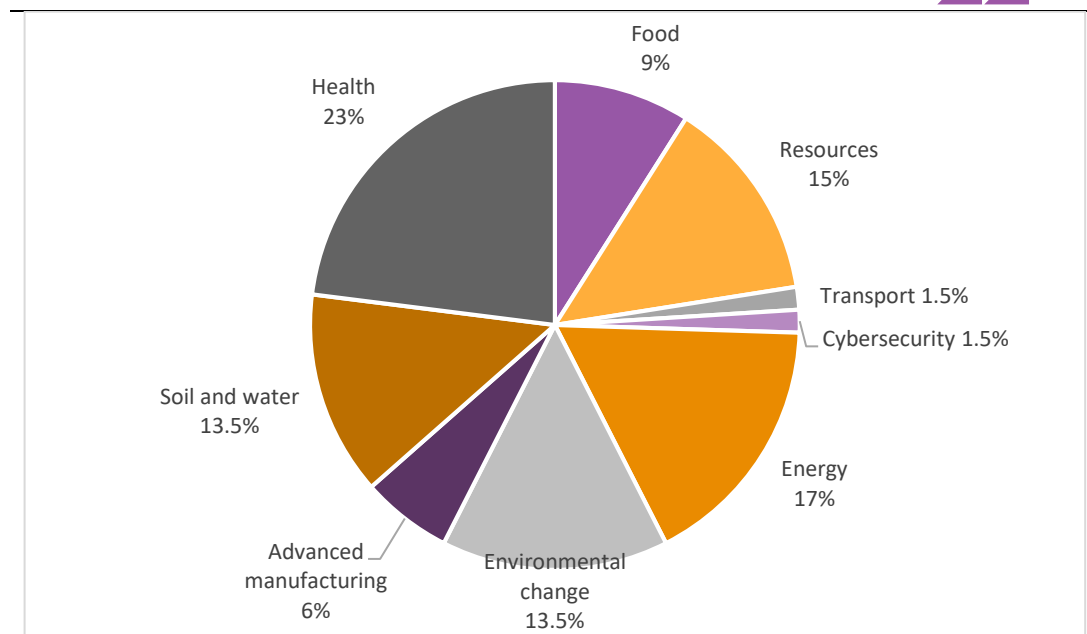
NOTE: SEVERAL CASE STUDIES ALIGN WITH MORE THAN ONE PRIORITY.

SOURCE: ACIL ALLEN

Over two thirds of the 2017 case studies addressed the following four priorities: food; environmental change; health; and resources.

Figure 2.4 shows the proportion of 2018 case studies that address the various priorities. Again, a significant proportion of the 2018 case studies (60 per cent) addressed the food, environmental change, health and resources priorities. It is worth noting that the energy priority was addressed by the second largest number of 2018 case studies (after health).

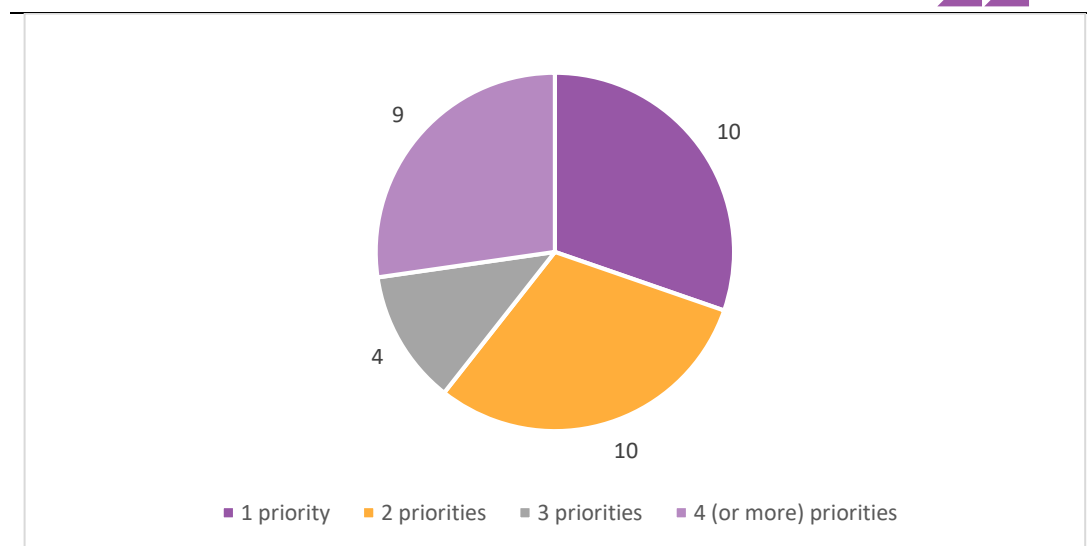
FIGURE 2.4 2018 CASE STUDY ALIGNMENT WITH NATIONAL SCIENCE AND RESEARCH PRIORITIES



Note: Some case studies align with more than one priority
 SOURCE: ACIL ALLEN

Figure 2.5 shows the number of 2018 case studies that address one, two, three and four or more priorities.

FIGURE 2.5 NUMBER OF SCIENCE PRIORITIES ADDRESSED BY THE CASE STUDIES



SOURCE: ACIL ALLEN

Ten case studies align with one of the priorities, ten align with two priorities, four align with three priorities, and nine align with four or more priorities. While the 2018 case studies are only a small fraction of CSIRO’s activities, the coverage they provide across the science priorities illustrates the breadth of CSIRO’s research.

2.3 Innovation outcomes

Many of the case studies identified ways in which the application of the research done by CSIRO was helping to catalyse innovation. Innovations identified in the case studies examined for the update report include new materials, new methods and new fundamental discoveries. Some innovations are improvements upon existing products, whereas others are novel applications or commodities. These innovations span a range of sectors. For example:

- Innovations in healthcare include improved management of chronic conditions, new approaches to disease detection and treatment, and increased efficiency of healthcare provision.
- Improvements in resource exploration, extraction and production have been realised through new resource discovery and mapping techniques, novel approaches to product sorting and processing, and new ways to extract value from what might otherwise be regarded as mining waste.
- The agricultural sector and the environment have benefited from refined pest control techniques, better land-use management, enhanced knowledge of water-flow and erosion patterns, and improved biosecurity measures.
- Power generation has been improved through new fuel sources, enhanced methane recovery and more efficient renewable energy technology.
- Innovations relevant to the health sector include increased efficiency of protein production and new materials and technologies for enhanced detection of biological and chemical compounds. These will benefit to the manufacturing and biotechnology industries.

2.4 Policy outcomes

Several the projects examined for the Update Report generated outputs that helped to inform policy development and decision making. Examples of case studies where this was the case include:

- GISERA – the Aquifer Managed Recharge using CSG Produced Water project. The project has provided scientific knowledge to underpin decision-making in relation to the operation of CSG wells at Reedy Creek and other comparable locations.
- Northern Australia – the TranSIT and FGARA projects. TranSIT provided the evidence to support decisions regarding selecting the most efficient stock transport routes, while still protecting the health of the cattle being transported. FGARA outputs enabled decisions to be made regarding the sustainable use of water in the Fitzroy and Gilbert catchments.
- The Clinical Terminology Tools project has influenced healthcare data collection policy.
- The Future Grid Forum has helped develop key policies to underpin reliable provision of Australia's future energy demands.

2.5 Impact and Cost Benefit Analysis

This section presents a summary of the cost-benefit analysis results from the CSIRO case studies undertaken since the 2017 report.

There were several case studies where a quantification of benefits was not possible due to data limitations or commercial confidentiality concerns, namely the ARCF, Community wellbeing (GISERA), Foot and Mouth, Aquifer managed recharge (GISERA), Impromy, LIGO, Patient Admission Prediction Tool, and Textor case studies. These case studies are therefore omitted from the table.

We have done the cost benefit analysis from two perspectives. The first does the analysis considering the costs incurred by all participants in the projects. The results are shown in **TABLE 2.1**. Whereas **TABLE 2.2** shows the results of the CBA analysis based on the costs incurred by CSIRO alone.

TABLE 2.1 SUMMARY OF CBA RESULTS FROM CSIRO CASE STUDIES UNDERTAKEN SINCE 2017 REPORT – FROM PERSPECTIVE OF ALL ORGANISATIONS PARTICIPATING IN THE PROJECTS

Case study	Analysis period		Benefits per year	PV benefits	PV costs	NPV	BCR
	Start year	End year	(2017/18\$m)	(2017/18\$m)	(2017/18\$m)	(2017/18\$m)	(2017/18\$m)
ACIL Allen Consulting							
Boron Molecular	2013/14	2036/37	Varies	297.46	2.8	294.7	107.49
Concentrating Solar Power	2009/10	2035/36	Varies	205.03	5.7	199.5	36.08
Distal Footprints	2012/13	2036/37	Varies	19.43	4.7	14.8	4.14
GISERA – Agriculture Land Management	2012/13	2036/37	Varies	6.1	1	5.1	5.85
Lab-at-Rig	2011/12	2026/27	Varies	578.8	32.1	546.8	18.05
Northern Australia	2011/12	2026/27	Varies	102.4	11.0	91.4	9.29
Oventus	2012/13	2035/36	Varies	5,745.6	10.2	5,735.5	565.16
Protein Production Facility			>=\$36.35				
Reflexivity	2015/16	2026/27	Varies	26.36	0.14	26.2	195.3
CSIRO							
Biomarkers for detection of colorectal cancer	2016/17	2026/27		1815.7	374.8	1440.9	4.8
Biosensors for Health and Food: Cybertongue / Cybernose	2017/18	2027/28		60.9	20.7	40.2	2.9
Clinical Terminology Tools	At maturity		734.77				
Direct Injection Carbon Engine ³	2017/18	2050/51				343.5	5.1
Dry Slag Granulation	2017/2018	2027/28		117.7	106.2	11.5	1.11
Foot and Mouth Disease	10 years			1940.8			
Future Grid Forum & Electricity Network Transformation Roadmap	2016/17	2050/51		15198	1526.5	13671.6	10
High Pressure Processing	1998	2018		623.4	267.0	356.4	22.2
Iron Ore Sintering	2001/02	2027/28		2314.2	56.4	2257.8	41
MR Ore Sorter	2017/18	2027/28		106.6	45.3	61.3	2.4
Rabbit Biocontrol	2016/17	2026/27		301.6	55.6	246	5.4

³ This is for DICE comparative to Brown Coal, the most profitable potential avenue identified for this research.

Case study	Analysis period		Benefits per year	PV benefits	PV costs	NPV	BCR
Reservoir Rejuvenation Technology	2008/09	2030/31		125.2	38.3	89.9	3.27
Weed Biocontrol	Varies	Varies		4184.5	98.5	4083	42.5 ⁴
CIE							
Total Wellbeing Diet Online	2015/16	2030/31				50.9	2.3
Care Assessment Platform / MoTER cardiac rehabilitation program	10 years			192.3	46.7	145.6	4.12
Vaximiser	10 years			58.9	17.8	41.1	9.6

NOTE: Numbers may vary due to rounding.
SOURCE: ACIL ALLEN

TABLE 2.2 SUMMARY OF COST-BENEFIT ANALYSIS RESULTS FROM CSIRO CASE STUDIES UNDERTAKEN SINCE 2017 REPORT – FROM PERSPECTIVE OF CSIRO

Case study	Analysis period		Benefits per year	PV benefits	PV costs	NPV	BCR
	Start year	End year	(2017/18\$m)	(2017/18\$m)	(2017/18\$m)	(2017/18\$m)	(2017/18\$m)
ACIL Allen Consulting							
Boron Molecular	2013/14	2036/37	Varies	148.73	1.75	146.99	85.03
Concentrating Solar Power					R&D cost breakdown not available		
Distal Footprints	2012/13	2036/37	Varies	9.72	2.13	7.59	4.56
GISERA – Agriculture Land Management	2012/13	2036/37	Varies	3.05	0.52	2.53	5.88
GISERA – Aquifer Managed Recharge using CSG Produced Water			Not quantified				
GISERA – Community wellbeing			Not quantified				
Lab-at-Rig	2011/12	2026/27	Varies	165.37	5.50	159.87	30.04
Northern Australia	2011/12	2026/27	Varies	100.09	1.33	98.76	75.12
Oventus	2012/13	2035/36	Varies	2,872.83	0.27	2,872.56	10,818.72
Protein Production Facility			>=\$36.35				
Reflexivity	2015/16	2026/27	Varies	26.36	0.14	26.23	195.30
CSIRO							
Biomarkers for detection of colorectal cancer	2016/17	2026/27		181.54	13.74	167.8	13.3

⁴ ACIL Allen's calculation as not done in original case study.

Case study	Analysis period		Benefits per year	PV benefits	PV costs	NPV	BCR
Biosensors for Health and Food: Cybertongue / Cybernose	2017/18	2027/28		54.8	10.1	44.7	5.4
Clinical Terminology Tools	At maturity		183.7				
Direct Injection Carbon Engine	2007/08	2050/51			41.22		3.5
Dry Slag Granulation	2017/2018	2027/28		47.78	5.46	42.32	1.41
Future Grid Forum & Electricity Network Transformation Roadmap	2016/17	2050/51		33.04	3.27	27.76	10
High Pressure Processing	1998	2018		473.8	121.1	352.7	3.9
Iron Ore Sintering	2001/02	2027/28		809.98	19.75	790.23	40.4
MR Ore Sorter	2017/18	2027/28		73.24	3.29	69.95	13.4
Rabbit Biocontrol	2016/17	2026/27		84.5	7.09	77.41	11.9
Reservoir Rejuvenation Technology	2008/09	2030/31		6.61	1.57	5.04	4.21
Weed Biocontrol	Varies	Varies					
CIE							
Total Wellbeing Diet Online	2015/16	2030/31				19.8	9.3 ⁵
Care Assessment Platform / MoTER cardiac rehabilitation program	10 years		192.3	46.73	145.57		4.12
Vaximiser	10 years		58.88	17.78	41.1		9.6

SOURCE: ACIL ALLEN

2.5.1 Estimating the annualised benefits from CSIRO research

One way of considering the return on the 'investment' in CSIRO is to look at in terms of the annual rate of return achieved from the rolling annual investment in the organisation. CSIRO's operating expenditure in 2017/18 was around \$1.3 billion, of which over 61 per cent is government funding, with the remainder being generated internally or coming from various partnering arrangements with industry and various government agencies.

CSIRO manages a large and diverse portfolio of research activities. Those activities evolve in ways that reflect the national science priorities and the research challenges identified by governments and industry. Over time, some areas of research are completed, and the findings are disseminated to industry and other users, other areas may not deliver what was expected and resources might be redirected towards new or emerging research priorities. However, we have assumed that the research portfolio has evolved to a point where it is reasonably stable in its performance characteristics through time. In effect, the outcome is a rolling investment strategy with a relatively steady flow of benefits.

However, as with any substantial portfolio of research, there will be occasional major breakthroughs that deliver very high value. It is reasonable to characterise the CSIRO as having a portfolio that

⁵ This case study was done with a discount rate of 5 per cent. Others all used 7 per cent.

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 examined in this review. Each of the investments in a research project involves investment over several years that can be translated to an average level of annual expenditure. Successful research projects yield impacts with value that will typically accumulate over many years into the future (that value can be calculated in present value terms). This 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.

Previous reports by ACIL Allen and 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.

For the 2017 report, ACIL Allen argued that it was 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 that report. This suggested that the total annual benefits from CSIRO's research would exceed \$6 billion. By comparing this figure with CSIRO's annual operating expenditure this implied that the expected ratio of return to CSIRO's research as a whole was around 5:1.

The present value of the estimated benefits per year of R&D totalled \$1,275.5 million for the twenty-one projects it was possible to value for this 2018 Update Report. This is lower than the \$3.2 billion estimated in the 2017 report. However, there were more projects examined for the 2017 report and five of those projects delivered very large annual benefits (AAHL - FMD (\$667.4 million), SIEF - early nutrition (\$567.6 million), SIEF - plant yield (\$750.4 million), SIEF - synchrotron (\$241.5 million) and Climate Adaptation Flagship - climate ready crops (\$234.1 million)).

In the case of the 2018 update, only two projects delivered very large annual benefits: Oventus (\$574.6 million) and Clinical Technology Tool (\$367.4 million).

Nonetheless, the estimated annual benefit of just these twenty-one new projects still comfortably exceeds the annual funding provided by the Commonwealth (\$793.5 million) and almost matches the total budget of the CSIRO (\$1,292.7 million). The fact that the twenty-one projects that it was possible to value for this 2018 Update Report generated almost \$1.28 billion in estimated benefits per year of R&D adds further weight to the argument that the benefits identified in these case studies represent but a fraction of the total benefits being generated by CSIRO's research.

If we assume (as for the 2017 report) that the annual value delivered by all other CSIRO research would at least match that delivered by the 21 case studies this would suggest that the total annual benefits from CSIRO's research would be around \$2.6 billion. Comparing this figure with CSIRO's annual operating expenditure suggests that the expected ratio of return from CSIRO's research was around 2:1. If we consider the return on investment from the government's contribution to CSIRO's budget then the ratio increases to over 3.2:1

Clearly, this is less than the 5:1 ratio estimated in 2017. However, this is not surprising given the uncertain nature of research. It is highly probable that similar reviews in future will sometimes identify outcomes and impacts that lead to higher ratios and at other times the ratio might be lower.

2.6 Other ways that CSIRO delivers value

The 2017 report identified several other sources of value that were not captured in the analysis of the case studies. Many of the case studies examined for this report have also generated value above and beyond the economic benefits identified. Some of these other sources of value are discussed below.

2.6.1 Increased collaboration

As noted in the 2017 report, collaboration is established as an important feature of modern science.⁶ The role that inter-institutional collaboration plays in enabling scientific progress is also important.⁷ In an increasingly globalised world, such collaborations include partnerships with local and international scientific research organisations, universities, and private businesses.

The majority of the research for the case studies in this update report involved collaboration with universities and other research organisations, in Australia and overseas. Such collaborations occur when there is a need to bring particular research skills into the team. Working together can also reduce the financial costs of research. For example, sharing expensive research infrastructure can help enable projects to proceed that might otherwise have been too expensive to undertake.⁸

CSIRO also often collaborates with businesses. Partnerships with business can arise in a number of ways. They can result from a direct approach to CSIRO by a business to get help to address a problem identified by that business. Alternatively, a collaboration might arise when a research project's results emerge, and efforts are made by CSIRO to identify a pathway to commercialisation.

Importantly, knowledge, market and network spill-overs may occur as a result of collaboration. This can give rise to academic and economic gain.⁹ In particular, 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.¹⁰

It was possible to identify the number of collaborators for 25 of the projects examined in this report. Figure 2.6 shows the results of doing so. Twenty-four of the CSIRO projects had one or more collaborators.

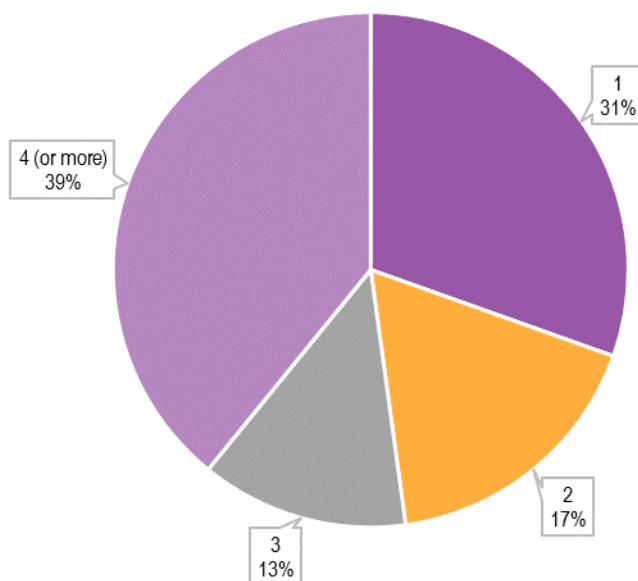
⁶ Science Europe (2014). *Life, Environmental and Geo Sciences Committee Opinion Paper: Career Paths in Multidisciplinary Research*. Belgium: Brussels.

⁷ 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.

⁸ Rolin, K. (2015). *Values in Science: The case of scientific collaboration*. Philosophy of Science, 82(2), pp. 157-177.

⁹ European Commission (2015). *Value of Research*. Luxembourg: Publications Office of the European Union.

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

FIGURE 2.6 NUMBER OF COLLABORATORS

Note: Only one project could be identified as have no collaborators involved.

SOURCE: ACIL ALLEN

There is evidence that international collaboration should be encouraged, as it can contribute to the completion of high-impact science.¹¹ A study by Clarivate found that:

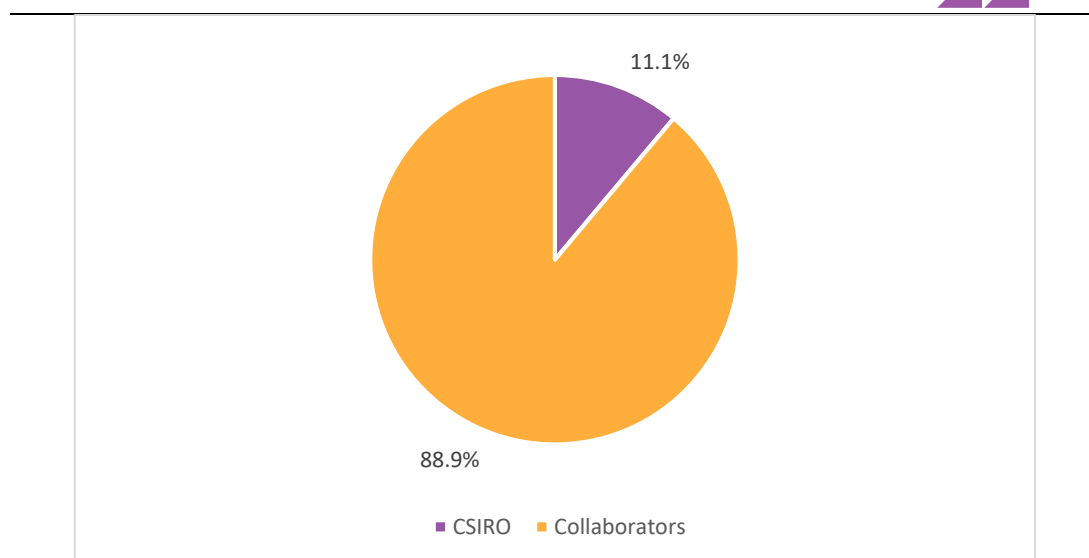
International collaboration boosts the citation impact of Australian research by 24 per cent.¹²

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, almost 90 per cent of the funding for research projects was provided by collaborators (see Figure 2.7).

¹¹ Op. cit. Smith et al.

¹² Clarivate Analytics InCites™, Department of Industry, Innovation and Science analysis, December 2016.

FIGURE 2.7 SHARE OF FUNDING PROVIDED BY COLLABORATORS

Note: The result is somewhat skewed due to a number of large expensive projects with substantial external funding

SOURCE: CSIRO CASE STUDIES

2.6.2 Training and education provided by CSIRO

Education and training is an important part of the nation's economic, intellectual and social development.¹³ CSIRO provides considerable training and education to support the next generation of Australian researchers. The bulk of that support is provided to STEM students.

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.

Three of the projects specifically identified that researcher training had occurred over the course of the project. This is less than 10 per cent of the projects examined for this update report. However, we expect that this figure under reports the actual training provided, as case studies do not consistently report whether training is provided (or not).

Of course, CSIRO continues to provide its Education and Outreach program. For over 35 years, CSIRO has provided innovative learning opportunities to schools, teachers and the wider community through programs such as the Creativity in Research, Engineering, Science and Technology (CREST), the STEM Professionals in Schools program, the CSIRO Discovery Centre and the indigenous STEM Education project.

2.6.3 Building public understanding and trust

The provision of information to the public through many of the research projects is not only providing educational services, but also helps to enhance public trust and support organisations' and firms' social licence to operate.

For example, the research outcomes achieved in the GISERA 'Making tracks' project increased the knowledge about the impacts of CSG (coal seam gas) access tracks in affected communities and how to reduce those impacts.

The project also provided a forum for farmers and other rural community members to express their concerns about CSG and its range of economic, social and environmental impacts. These

¹³Australian 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.

conversations provided both farmers and CSG companies with the opportunity to better understand each other's concerns and helped to build and maintain trust between the parties.

A stakeholder interviewed for the case study commented that:

...the fact that a lot of the intensity has gone out of the arguments around CSG suggests that the information provided as a result of GISERA's research has helped to cool down the debate.

Another stakeholder when asked if the GISERA research is helping to inform collaboration and engagement between industry, government & communities to address challenges and opportunities and develop solutions responded:

I do – the work GISERA is doing is on the ground in communities and they – independent scientists – work with people in the communities talking with them about their concerns.

The Reflexivity case study provides another example in this area. Reflexivity is a technology platform and community engagement model that provides resource companies with real-time insights into the sentiment of members of the communities that they work in. Using this information, companies can benchmark and track their social performance at individual operations and across the enterprise as a whole. It also gives communities a new voice that can be heard by various management levels within those companies.

Reflexivity has been adopted by Rio Tinto at a mine site in the Pilbara. It is also being used by Terramin Australia Limited in the Adelaide Hills, and Canadian firm Yamana Gold in Brazil. It is hoped that these early projects demonstrate the value of Reflexivity and as a result other mine sites operated by these companies will also adopt Reflexivity to measure and track their performance.

Anglo American used Reflexivity data to track sentiment among local communities at a troubled platinum mine in South Africa. It helped improve trust within the community to levels very similar to three other high functioning mines in South Africa. The data provided to the mine shaped who and how to engage local communities to address relevant issues, it helped avoid conflicts that had beset other similar mining operations in the same platinum mining region. Community members and company personnel reported the process was completely novel, powerful, and inspired a new way of relating to each other



This section discusses a number of follow up actions identified in the course of preparing this update report. It also introduces a new study that seeks to develop a framework for assessing the impact that CSIRO research has on policy development, implementation and review.

3.1.1 Ensuring a consistent approach to case study preparation

Even though the preparation of case studies are required to adhere to the CSIRO's evaluation framework there remains some differences in how that framework is applied by some of the different groups that prepare case studies. As demonstrated by this update report, this means that it is not always possible to aggregate all the estimates of economic benefits that arise from the projects that are the subject of case studies.

Adopting a consistent approach to the way that economic benefits are estimated and reported would enable more robust estimates of the aggregate impact of CSIRO's research to be prepared.

3.1.2 Better reporting on researcher training

As discussed in the previous section, the training that CSIRO provides to Australia's future pool of researchers is a vital service to the economy. More consistent reporting of this training in the case studies would help to better demonstrate the important role that CSIRO plays in this area.

Information on the nature and amount of training provided as part of a project should be a standard inclusion in case studies.

3.1.3 A framework to assess the impact of research ON POLICY

CSIRO, in partnership with ACIL Allen is undertaking a pilot study to help better understand how to evaluate the impact that CSIRO-funded research has on public policy. The pilot study aims to answer the following questions:

- *How effective is CSIRO's engagement in policy processes?*
 - This question seeks to illuminate the process by which CSIRO research is adopted by end users (government) via a policy pathway, and whether current approaches (e.g. dissemination or outreach activities) have been effective. This question requires us to understand how it actually happens in practice: an investigation of who, what, where, when and how CSIRO engages with end users to facilitate adoption of research at different points in the policy cycle.
- *To what extent can policy outcomes be attributed to CSIRO?*
 - This question seeks to answer the question of how much of a policy outcome (adoption of CSIRO outputs into policies, regulations, others) can be attributed to CSIRO; and if possible, to assess the contribution of the policy outcome to downstream impacts using best-practice approaches.

The pilot study will examine CSIRO's contribution to the development and delivery of the Commonwealth Fisheries Harvest Strategy Policy and Guidelines (HSP). Ultimately, the pilot study will develop guidance for planning, monitoring and evaluating policy-oriented research, based on international best practice, and to build internal capacity to undertake future evaluation work which is applicable across any domain.

CSIRO has been invited to present a poster on the pilot study at a major international event on research evaluation, the Conference on *Impact of Research & Innovation Policy at the Crossroads of Policy Design, Implementation and Evaluation*. The conference will be held on 5-6 November 2018.



This appendix provides a summary overview of the 33 case studies prepared since the 2017 Value Report was completed. For each case study the following information is presented:

- The name of the case study
- The objective(s) of the research project
- The outcome(s) of the project
- The impact(s) of the project (economic (NPV and BCR), environmental and social)
- Any innovative element(s) of the project

All dollar values are in 2017/18 Australian dollars and written from the perspective of CSIRO.

A.1 Advanced Resource Characterisation Facility (ARCF)

Objective(s)

The ARCF was supported by the CSIRO's Science and Industry Endowment Fund (SEIF) program. Its objective is to provide a world-class research infrastructure hub that will allow researchers to have access to leading edge equipment for minerals research.

Outcome(s)

The research infrastructure is installed and operational, and a MOU for collaborative research has been signed between CSIRO and five West Australian universities. The ARCF provides an infrastructure hub for metre to atomic scale analyses within the National Resource Sciences Precinct.

Impact(s)

This project has resulted in increased Australian and international collaboration, a coordinated approach to equipment and infrastructure acquisition and use. There is growing interest and support from mining firms in the facility.

Innovation

The ARCF provides researchers access to world-leading equipment in a specialised research facility, including the world's first Maia Mapper (based on the award-winning Maia detector technology).

A.2 Australian e-Health Research Centre (AEHRC)

Objective(s)

The AEHRC aims to improve the efficient running of hospitals, support community healthcare, and improve clinical outcomes and research through improved virtual communication, use of predictive modelling, information collation and database management.

Outcome(s)

Multiple projects are in progress, are on trial or have been implemented by Australian hospitals, residential aged-care facilities and by patients in their homes.

Impact(s)

AEHRC's projects have improved healthcare management and efficiency, increased flexibility of and access to medical and rehabilitation services, improved patient health outcomes, provided databases for improved clinical research and the development of targeted treatments.

A.3 Biomarkers for detection of colorectal cancer

Objective(s)

This study aimed to provide improved early detection of colorectal cancer using biomarkers.

Outcome(s)

Novel colorectal cancer detection test COLVERA has been released on the US market and contracts made with private health insurance companies to provide access to it at a discounted rate. Communication and marketing of the product to oncologists and relevant healthcare providers is under way.

Impact(s)

Due to earlier detection, the test will reduce the healthcare burden as well as improve patient health outcomes. The project has also increased CSIRO's epigenetics and biomarkers research capacity. NPV of the project is \$167.8m and the BCR is 13.3.

Innovation

These innovative epigenetics and biomarker discoveries have led to new health treatments and improved research capacity.

A.4 Case study Biosensors for Health and Food: Cybertongue/Cybernose

Objective(s)

Cybertongue and Cybernose were developed with the aim of improving technology for the detection of chemical and biological compounds, including food contaminants and explosives.

Outcome(s)

Demonstration of the quality and economic viability of real-time, portable, on-site detection technology has led to partnerships with industry sectors such as dairy production and Defence.

Impact(s)

The impacts of this technology are numerous including: decreased food wastage; decreased spoilage and increased shelf-life of products; decreased cost for measuring odours and chemical or biological contaminants; improved biosecurity; increased processing efficiencies and lower capital costs. It also has national security applications, through enhanced detection of explosive substances. Rapid, real-

time and continuous on-site measurements also deliver enhanced decision-making capacity. NPV of the project is \$44.7m and the BCR is 5.4.

Innovation

The portable kit for on-site detection of biological and chemical compounds has cross-sectoral impact, by making real-time detection easier and more cost-efficient.

A.5 Boron Molecular

Objective(s)

The Boron Molecular project aimed to develop new chemicals and production of these at an industrial scale.

Outcome(s)

New, unique chemicals were created and commercialisation pathways developed, especially for the pharmaceutical industry.

Impact(s)

This research has been commercialised and job opportunities created. The new chemicals created have applications in the pharmaceutical industry, leading to potential health benefits. There is also a social benefit, as one of the novel compounds made can be used to preserve classical works of art. The NPV of the project is \$146.99m and the BCR is 85.03.

Innovation

The innovation in this project has been in the development of unique chemicals, and efficient production processes for their scalable manufacture.

A.6 Clinical Terminology Tools

Objective(s)

The Clinical Terminology Tools project aimed to develop a database of global clinical terminology to improve professional understanding and communication clarity.

Outcome(s)

The tools developed have been adopted by Australian hospitals, the Australian Digital Health Agency and the Royal Australasian College of Surgeons.

Impact(s)

The Clinical Terminology Tools have improved the consistency of standard clinical terminologies, reduced health system costs and improved health outcomes. The tools have also influenced healthcare data collection policy, improved productivity and efficiency, and produced revenue from licensing fees.

A.7 Concentrating Solar Power (CSP)

Objective(s)

This project aimed to improve the efficiency of concentrating solar power for energy production.

Outcome(s)

Larger, lower cost heliostats that are suitable for mass manufacture have been designed, as well as software that optimises heliostat positioning and energy generation. This has led to licensing agreements with industry for use of the technology in both domestic and international installations.

Impact(s)

Impacts include increased job opportunities and economic gain through export of the technology. Faster, cheaper and more efficient CSP plant installation and power generation may lead to increased use of renewable energy and higher levels of energy security, as well as lower CO₂ emissions.

Innovation

New cheaper to manufacture heliostat design and heliostat positioning optimisation software improves the economics of CSP energy generation.

A.8 Direct Injection Carbon Engine (DICE)

Objective(s)

The DICE project aimed to develop an alternative pathway to low emissions electricity generation from coal and biomass, pertinent given Australia's abundance of high-emissions brown coal.

Outcome(s)

DICE technology, which injects coal slurry (or in time, biomass) directly into a converted diesel engine for more efficient, lower emissions power generation, has been adopted by Australian and international electricity companies.

Impact(s)

Impacts include: lower capital costs for power generation; a new fuel type for national and international markets; reduced CO₂ emissions and water wastage; and increased energy security. The BCR is 3.5.

Innovation

DICE research has provided a new way of processing coal (and potentially biomass) for more efficient and less carbon intensive energy production.

A.9 Distal Footprints

Objective(s)

Distal Footprints aimed to provide better geoscientific data, allowing for increased resource discovery and recovery rates despite relatively deep top-cover.

Outcome(s)

This project resulted in improved characterisation of the subsurface layer, identification of key trace elements associated with ore deposits, geochemical mapping for predictive targeting and better GIS data, improving productivity and competitiveness for CSIRO's project funding partners.

Impact(s)

Distal Footprints reduces exploration costs and increases investment opportunities by providing more accurate information about the location of resources. It may aid regional development. The NPV of the project is \$7.59m and the BCR is 4.56.

Innovation

Novel imaging techniques have led to increased efficiency of resource discovery and extraction, even with relatively deep top-cover.

A.10 Dry Slag Granulation (DSG)

Objective(s)

The DSG project aimed to create a more efficient and environmentally-sustainable way to process slag (mineral-processing off-casts).

Outcome(s)

The new, air-dry granulation process has been patented and commercialised with a Chinese company, licensing fees established and agreements with two international companies made to trial the technology with non-ferrous slags.

Impact(s)

Economic impacts include increased productivity and efficiency through energy savings and novel applications of processed slag for the cement industry. Environmental and social impacts include reduced CO₂ and sulphur emissions, lower water use and reduced hazards associated with intense heat and molten slag. The NPV of the project is \$42.32m and the BCR is 1.41.

Innovation

The creation of an air-dry, centrifugally-forced granulation process uses substantially less water, reduces CO₂ and SO₂ emissions and allows for heat recovery, whilst also producing glassy slag for cement manufacturing.

A.11 Foot and Mouth Disease

Objective(s)

This project concentrated on improving surveillance, prevention and treatment of Foot and Mouth Disease (FMD).

Outcome(s)

Outcomes included adoption of improved surveillance measures, enhanced response capacity and potential for earlier detection in the livestock industry.

Impact(s)

Impacts include: economic benefit through avoided costs related to a FMD outbreak and sustained market access; a decrease in the number of animals slaughtered, with related environmental benefits and increased industry social licence to operate; and increased resilience of rural communities through lower-risk agriculture.

A.12 Future Grid Forum

Objective(s)

The Future Grid Forum aimed to develop and explore the potential of Australia's energy future.

Outcome(s)

The modelling results and advice have been adopted by Government, industry and the wider community.

Impact(s)

Impacts of the Forum include improved productivity and competition, decreased uncertainty in the sector and therefore improved decision-making capacity, and the potential for lower household energy bills. As well as promoting adoption of sustainable energy sources, the project could help ensure energy security and equity of access to, and availability of, energy. Capacity building and community education have led to knowledge diffusion and the creation of common understanding and to the potential for improved policy and implementation. The NPV of the project is \$27.76m and the BCR is 10.

A.13 GISERA – Agricultural Land Management***Objective(s)***

This project aimed to use aerial surveys and GIS to model terrestrial water-flow patterns, to minimise the impacts of the access tracks needed for coal seam gas (CSG) exploration and development.

Outcome(s)

The project has led to the development of best-practice approaches, improved erosion management, improved monitoring and better informed businesses, farmers and communities.

Impact(s)

The environmental and economic impacts of this project are numerous: reduced erosion and sediment flows into waterways; increased productivity from agricultural lands; decreased impact of CSG tracks through improved placement; lower track maintenance costs; improved land management practices by the CSG industry and through this, increased trust between landholders and the industry. The NPV of the project is \$2.53m and the BCR is 5.88.

Innovation

The capability to produce high resolution 3D maps using aerial images, as developed for this project, has attracted interest from a broad range of groups, with commercialisation being actively pursued.

A.14 GISERA – Aquifer Managed Recharge using CSG-produced Water***Objective(s)***

To study a safe and sustainable way to reinject treated wastewater produced during CSG extraction. This would allow for the managed recharge of underlying aquifers, allowing the reinjected water to later be used for other applications, such as irrigation for agriculture. Reinjecting treated water can aid the long-term sustainability of aquifers, but it is necessary to ensure that potentially harmful metals or metalloids are not mobilised during the process.

Outcome(s)

A new, detailed understanding of the geochemistry of aquifers was obtained, particularly the effect of oxidation on the mobilisation of metals.

Impact(s)

This project has enabled the sustainable operation of the Reedy Creek CSG wells, with its associated economic returns to industry, State Government royalties and contribution to Australia's GDP. The wells are expected to remain in operation for the next 30 years.

The reinjection processes developed has contributed to Origin Energy's social licence to operate in the area. The reinjected water has helped to reverse the decline of water availability from the Precipice Sandstone Aquifer. This has economic, environmental and social impacts, by increasing the amount of water available for crop irrigation in the area.

This project has delivered economic benefits, given that reinjection is less expensive than other alternatives. However, it was not possible to quantify these benefits.

A.15 GISERA – Community wellbeing and responding to change in the context of Coal Seam Gas development (2nd survey)

Objective(s)

This project aimed to understand and manage the impact of CSG exploration on affected communities.

Outcome(s)

Governments and industry now have an improved understanding of the current and future issues related to community wellbeing and resilience.

Impact(s)

This research has informed government and industry decision-making and community engagement, with its associated potential for improved social license to operate.

A.16 High Pressure Processing

Objective(s)

This project aimed to develop high-pressure processing as a method for improving food safety and quality.

Outcome(s)

CSIRO's safe alternative to thermal processing, which better maintains quality factors such as flavour and texture, has been taken up by industry partners such as Moira Mac's, Preshafood and Longfresh.

Impact(s)

Impacts include higher retail prices and increased consistency and quality of foodstuffs. Food safety is increased and food wastage decreased. The NPV of the project is \$352.7m and the BCR is 3.9.

A.17 Impromy

Objective(s)

This project aimed to improve health outcomes through an integrated weight-loss program, including meal replacements.

Outcome(s)

The program has been developed and adopted by consumers Australia-wide, in collaboration with industry partner Probiotec.

Impact(s)

Impacts include decreased health-system burden and increased personal wellbeing.

A.18 Iron Ore Sintering

Objective(s)

As Australia's known reserves of high-grade iron ore are mined, the mining industry must increasingly focus on the efficient extraction and processing of lower-grade ores. This research sought to provide

processes for the rapid characterisation of ores and sinters, including models for predicting sinter quality.

Outcome(s)

This research has led to more efficient and higher quality sinter production. This has in turn led to increased efficiency of steel production and improved the quality of the steel. Being able to maintain sinter quality when using lower-grade ores ensures continued worldwide acceptance of Australian iron ore exports.

Impact(s)

Impacts of this research include an increase in the quality and consistency of Australia's iron ore exports, increased national income through higher demand for these products and, as a result, improvement of Australia's balance of trade. It has further reduced industry input costs. The NPV of the project is \$790.23m and the BCR is 40.4.

Developing a better understanding of the properties of sinter fuels and potential alternatives to coke breeze may also reduce the CO₂ emissions and the energy required for sinter production and processing. These innovations could also lead to job growth in the mining and steelmaking industries.

Innovation

This research has uncovered previously unknown characteristics of Fe₂O₃ ores. Goethite, previously viewed as an undesirable component of sinter blends, has been shown to be of benefit to the sintering process.

A.19 Lab at Rig

Objective(s)

The Lab at Rig (LAR) project aimed to create an on-site alternative to drill core sampling, which would allow real-time analysis and characterisation of resources' geochemical properties.

Outcome(s)

LAR is now being trialled by multiple Australian and international companies. There is a partnership between Imdex and Barrick Gold to further test and develop the product. Commercialisation has been fast-tracked and patents obtained.

Impact(s)

The LAR project is expected to provide significant industry-wide savings to exploration budgets, reduce exploration time and associated risk. It should also accelerate the time between discovery of a resource and extraction. There is potential flow-through to increased government taxation and royalty revenues. The NPV of the project is \$159.87m and the BCR is 30.04.

Environmental benefits include a reduced exploration footprint (less drilling and fewer core samples are needed) and reduced CO₂ emissions (related to sample transport). This enhances exploration firms' social licence to operate.

Innovation

This potentially disruptive technology allows for real-time, on-site analysis to the same standard as XRD analysis (at a remote testing facility) at a reduced cost, both in terms of time and money. LAR is currently the only available version of this technology.

A.20 Laser Interferometer Gravitational-Wave Observatory (LIGO)

Objective(s)

CSIRO's involvement in the LIGO project was provision of optical equipment to assist detection of gravitational waves.

Outcome(s)

Development of a process for monitored coating deposition for optics manufacture helped to produce equipment that resulted in the first ever detection of gravitational waves. A discovery that has resulted in the awarding of a Nobel Prize.

Impact(s)

Participation in the project enhanced CSIRO's international reputation and improved inter-institutional links for further collaboration. This important fundamental research may have broad-reaching impacts, which are not yet evident. The new process for optics manufacturing may also have industrial applications.

Innovation

This innovative, real-time monitoring and optimisation technique for optics manufacturing allowed measurement of gravitational waves.

A.21 Magnetic Resonance Ore Sorter

Objective(s)

This project aimed to use magnetic resonance (MR) technology to improve the grading and sorting of bulk ore, as lower-quality ores are increasingly relied upon to satisfy global demand.

Outcome(s)

The MR Ore Sorter has been shown to improve the efficiency of ore grading and sorting, especially with reference to copper and gold extraction. The product has been patented, is in preparation for commercialisation, potential clients have been identified and contracts are expected to commence in 2019.

Impact(s)

This project has a range of potential economic, environmental and social impacts. Improved productivity and efficiency combines to increase access to resources, by making extraction of low-grade ore deposits more economically viable. This may help to secure existing markets and thereby improve national economic performance. The NPV of the project is \$69.95m and the BCR is 13.4.

The innovation allows for greater access to resources, increases mine lifetimes (and thus associated jobs), reduces energy consumption per unit output, decreases water consumption and CO₂ emissions, and reduces mine tailings. Reducing the need for new cuttings also increases habitat conservation.

Innovation

This world-first application of MR technology has the potential to fundamentally transform mining operations, improving the efficiency and profitability of high-tonnage operations, and can be retrofitted to existing grading systems.

A.22 Northern Australia

Objective(s)

The Northern Australia project aimed to produce improved, evidence-based assessment tools for land-use, water and infrastructure planning and transport logistics in the Northern Territory.

Outcome(s)

New planning tools (TraNSIT and FGARA) have been used by Government and industry across Australia to evaluate the relative merits of proposed new infrastructure and policy interventions.

Impact(s)

The potential for new developments provides improved job opportunities. Environmental benefits include better land and water management practices and more efficient use of transportation networks. The NPV of the project is \$98.76m and the BCR is 75.12.

Innovation

This innovation allows for more accurate assessments of applications for land and water-use developments, new infrastructure and policy changes.

A.23 Oventus

Objective(s)

Oventus aimed to improve treatment for sufferers of obstructive sleep apnoea.

Outcome(s)

The therapeutic goods administration (TGA) and the US Food and Drug Administration (FDA) have approved the new medical device, which is now marketed in Australia and the USA. A new partnership with a Chinese firm has led to plans to introduce the device to the Chinese market.

Impact(s)

The invention has large projected revenue from domestic and international sales, with a NPV of \$2872.56 and a BCR of 10,818.72. In addition to new employment opportunities, the device will improve patient health outcomes and, as a cheaper alternative, may improve equitable access to healthcare.

Innovation

This project has provided a new, cheaper approach to obstructive sleep apnoea treatment.

A.24 Patient Admission Prediction Tool (PAPT)

Objective(s)

PAPT aimed to improve emergency hospital care through better triaging and logistical planning, by predicting patient arrivals, treatment required and proposed discharge time.

Outcome(s)

The predictive software developed has been adopted by Australian hospitals.

Impact(s)

Impacts include: better hospital bed management systems; less overcrowding in the Emergency Department; increased efficiency of treatment provision; improved staff productivity; improved health outcomes, for staff and patients, and increased research capacity.

Innovation

This innovative project has included the development and validation of a predictive mathematical model to improve ED preparedness and processes.

A.25 Protein Production Facility

Objective(s)

This project aimed to produce new proteins for the biotechnology sector.

Outcome(s)

The Protein Production Facility had resulted in enhanced protein production capability and new health treatments, including international vaccine development and cancer treatments.

Impact(s)

Support for research, education and training was provided, as well as new jobs through the growth of the biotechnology sector. Socially, this research provided new pharmaceutical products and ensuing health benefits, as well as environmental benefits through improved biosecurity measures. The quantifiable benefits attributable to the CSIRO Protein Production Facility were estimated to be at least \$36.65 million per annum. This is 8.5 times the average annual cost of the Facility.

Innovation

This facility has helped produce novel treatments (for cancer and eye disease) and base compounds for use in the biotechnology sector.

A.26 Rabbit Biocontrol

Objective(s)

This project aimed to improve biological control of rabbit populations.

Outcome(s)

The outcome was a coordinated release of new viral strains, an effective method as part of a long-term control strategy.

Impact(s)

Rabbit Biocontrol will decrease damage to agricultural land as well as lowering the cost of rabbit control measures. This will improve job stability and profit for agricultural sector workers. Environmental benefits include increased biodiversity and decreased soil damage, erosion and water-quality issues. The NPV of the project is \$77.41m and the BCR is 11.9.

Innovation

New understanding of the molecular epidemiology, evolution and species-specificity of caliciviruses has resulted in new and improved biological control agents for rabbits.

A.27 Reflexivity

Objective(s)

Reflexivity is a software package and consultation framework that assists in community engagement initiatives. This helps business to collate and assess community sentiment towards planned or current projects and to identify, and address, community concerns. Participating in CSIRO's ON accelerator program aimed to support the commercialisation and long-term financial sustainability of this innovative product.

Outcome(s)

Participation in the CSIRO ON program resulted in the development of a subscription model, which aided the scalability and worldwide applicability of the package. Ensuring the retention of data collected means that longitudinal studies can be conducted. The program has been adopted by several firms.

Impact(s)

This collaboration has led to improved social impact management plans, increased community trust and engagement, and influenced the shaping of community investment and engagement strategies. This has increased operators' ability to secure and maintain their social licence to operate, through being able to show regulatory bodies support from the wider community and to address their concerns. It may also prevent operational delays by improving companies' ability to counter arguments presented by activists. The NPV of the project is \$26.23m, with good potential for further commercialisation, and the BCR is 195.3.

Innovation

This novel method of communicating with communities is unique in its approach. Due to its method of multi-year licencing and retention of data, information can be aggregated to give companies access to both baseline data and long-term trends.

A.28 Reservoir Rejuvenation Technology

Objective(s)

This research aimed to design a method for the rapid replenishment of methane in coal seams.

Outcome(s)

Novel methods for improved methane replenishment through the introduction of methanogenic bacteria have been adopted by Australian and international CSG extraction companies.

Impact(s)

This has resulted in increased methane content and reservoir longevity, more efficient production of CSG, a decreased environmental footprint and possible use as a transition fuel to renewable energy. The technology further improves energy security and firms' social license to operate. The NPV of the project is \$5.04m and the BCR is 4.21.

Innovation

This means of reservoir rejuvenation has overcome challenges not yet solved by other approaches on the market.

A.29 Textor

Objective(s)

The Textor project led to the development of new materials for disposable nappies for newborns.

Outcome(s)

The new, moisture-wicking material invented provided increased turnover and profit for partners Textor Tech and Kimberly-Clark.

Impact(s)

This research increased the productivity of manufacturing processes, increased exports and employment opportunities, and the stability of the business and resulted in investment in plant equipment. Health and environmental benefits include reduced skin irritation and less waste to landfill. There are also potential Defence and further health application for the wider research project.

Due to concerns around commercial confidentiality it was not possible to carry out a cost benefit analysis. However, Textor's turnover was reported to be \$22 million in 2012. This CSIRO developed technology has helped to ensure Textor's financial viability.

Innovation

The design of a new, moisture-wicking material has multiple applications across the Defence and health sectors.

A.30 Total Wellbeing Diet Online (TWD)

Objective(s)

The TWD aimed to improve Australians' health outcomes through better diet.

Outcome(s)

The online diet program developed has been adopted by dieters, including high-risk groups such as diabetics or those with cardiovascular diseases.

Impact(s)

Impacts include: increased productivity through decreased incidence of chronic diseases; risk reduction for diabetes, cardiovascular diseases and all-cause mortality; reduced spending on Type 2 diabetes management; reduced dependence on medications; and improved life quality associated with weight loss. The NPV of the project is \$19.8m and the BCR is 9.3.

A.31 Care Assessment Program/MoTER

Objective(s)

The project aimed to improve access to, and uptake of, cardiac rehabilitation programs.

Outcome(s)

CSIRO holds an exclusive patent to the mobile technology and software that provides information to patients, motivates them and tracks their progress.

Impact(s)

MoTER reduces rehabilitation and healthcare costs, increases productivity through faster recovery rates and increases rehabilitation access and uptake. Initial assessments suggest that MoTER is as beneficial as a hospital-based programs and increases consumer health-care choices. The NPV of the project is \$145.57m and the BCR is 4.12.

Innovation

This innovative, mobile technology may change the way cardiac post-care is managed and implemented.

A.32 Vaximiser

Objective(s)

Vaximiser aimed to improve influenza vaccine production.

Outcome(s)

A new method has been patented, improving the efficiency of vaccine production domestically and overseas.

Impact(s)

Impacts include: increased access to vaccinations; decreased cost per unit; health benefits and increased productivity through decreased illness; increased ability to respond to pandemics; and improved reputation and connections with the international market. The NPV of the project is \$41.1m and the BCR is 9.6.

Innovation

A new, genetically-modified brood of chickens has been bred, whose eggs are used to more efficiently produce influenza vaccine.

A.33 Weed Biocontrol

Objective(s)

This research worked to improve biocontrol of invasive plants.

Outcome(s)

Improved biological control agents, education and decision-making processes were adopted by interested parties both in Australia and internationally.

Impact(s)

Economic benefits of this research included improved agricultural production and decreased cost of weed control measures, as well as increased income and employment opportunities in rural areas. Environmental benefits include increased biodiversity and improved soil and water quality.

Innovation

New control agents have improved agricultural production and management of invasive species, both domestically and overseas

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