ACIL ALLEN CONSULTING

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SIEF IMPACT REVIEW

APPENDIX 1 – SIEF IMPACT CASE STUDIES

FINAL

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

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EXECUTIVE SUMMARY

This report assesses SIEF's impact and value through seven case studies.

Five Research Projects (Energy Waste, Early Nutrition, Plant Breeding, RAFT for medical applications, and Distal Footprints) were selected as case studies for this report. The eReefs Research Project, which was examined as part of a previous analysis of the impact and value of CSIRO's research, was also included.[1] A Special Research Program activity (Synchrotron Science) and a Research Infrastructure Program activity (Advanced Resources Characterisation Facility (ARCF)) were also selected as case studies for this report. The full case studies for the five Research Projects and the Special Research activity are provided in appendices to this report.

The conservatively estimated net present value of the case studies in this report exceeds $4 billion over the next 20 years.

Table ES 1 summarises the results of the benefit cost analysis conducted for each activity. No results are provided for the ARCF as it is too early in the activity to estimate the value it might deliver.

TABLE ES 1 SUMMARY OF COST BENEFIT ANALYSIS RESULTS

Case study	PV of SIEF funding	PV of benefits	NPV	BCR
	($m)	($m)	($m)	
Energy waste	$7.3	$151.6	$144.3	20.8
Early nutrition	$6.2	$428.2	$422.0	69.1
Plant breeding	$6.2	$2,825.3	$2,819.1	459.5
RAFT for medical applications	$4.8	$53.2	$48.4	11.1
Distal footprints	$4.3	$23.4	$19.2	5.4
eReefs [a]	$4.3	$11.9	$7.6	2.8
Synchrotron Science [b]	$11.9	$811.2	$799.3	68.3
Seven case studies	**$44.9**	**$4,304.9**	**$4,259.9**	94.8

[a] The data for the eReefs case study is based on the results of earlier work by ACIL Allen which examined the impact and value of CSIRO research. The eReefs project was funded in part by SIEF; and to arrive at the figures above, 10% of the estimated benefits of eReefs has been allocated to SIEF. [b] The estimate of the value of Synchrotron Science is based on only three of over 200 projects and is therefore conservative.

SOURCE: ACIL ALLEN CONSULTING

Research Projects

The estimated net present value (NPV) of the six Research Projects (including eReefs) is $3.5 billion in 2016-17 dollars. These are very substantial benefits. In fact, any one of the first

[1] For a detailed analysis of the eReefs Research project, please refer to http://www.csiro.au/en/About/Our-impact/Our-impact-in-action/Latest-impact-case-studies.

three projects listed in **Table ES 1** are estimated to have returned benefits that would largely or fully offset the full amount spent by SIEF on all of its various programs.

Some benefits could not be quantified at present and are expected to be significantly greater over time.

Furthermore, there were a number of potential benefits associated with the selected case studies which we were unable to quantify, either because it was still too early to do so, or because of commercial confidentiality. Hence, there are strong arguments that a number of the case studies in this report could deliver substantially higher benefits than those identified above.

It is possible that some of the estimated benefits may not eventuate or may take longer to eventuate than previously thought. However, with so many paths towards delivering benefits being actively explored, coupled with the fact that only a subset of all the Research Projects supported by SIEF has been examined, ACIL Allen is confident that the eventual benefits of the Research Projects will easily exceed their costs and, most probably, also exceed the total cost of the SIEF Portfolio.

Special Research Program

From time to time SIEF funds activities which align with its purpose and strategic objectives, but which fall outside of the scope of its other programs. These activities are covered under the Special Research Program. To date two such activities have been funded. One of these, Synchrotron Science, was selected as a case study for this review.

The estimated benefit cost ratio for the SIEF Synchrotron Science activity was more than 68.

Over the period 2012 to 2016, SIEF's funding of the synchrotron supported 243 research projects. The majority of these projects related to the minerals, health, manufacturing, and energy sectors. The potential benefits of three of these projects were analysed in greater detail and the results are shown in **Table ES 1**. These three projects included the assessment of gold in eucalypt leaves, the discovery of a new pharmaceutical for treating blood disorders, and the examination of the nanostructure of casein micelles. The estimated benefit cost ratio for the Synchrotron Science activity was over 68.

While the other 240 projects conducted using the synchrotron have not been examined in sufficient detail to estimate their benefits, it is highly likely that, over time, they too will deliver significant benefits. Given this, the benefits described above are probably an underestimate of the total benefits likely to flow from the synchrotron research.

The other projects that were able to use the synchrotron as a result of the SIEF funding could reasonably be expected to deliver benefits similar in value to those estimated to flow from the three projects examined as part of this case study.

A value has not been assigned to the other Special Research activity supported by SIEF (the Australian Square Kilometre Array Pathfinder (ASKAP)). However, it is clear that it has already delivered a number of benefits in terms of employment opportunities and exports. This strengthens the confidence that this element of the SIEF portfolio of activities will deliver benefits that exceed the cost of the Special Research Program, and most probably the total cost of SIEF.

Research Infrastructure Program

SIEF provided a $12.4 million grant as part of its Research Infrastructure Program to establish the Advanced Resource Characterisation Facility (ARCF). The SIEF funding enabled the purchase and installation of three items of equipment at three sites in Perth. The equipment will be used primarily to conduct research that will support minerals exploration and processing.

Even at this early stage, significant economic, social and environmental benefits from ARCF have been assessed as highly likely.

The SIEF-funded research infrastructure has only relatively recently been commissioned and begun to be used by researchers. However, a number of interesting projects are already underway. The researchers using the equipment believe that there is a high likelihood that these projects will deliver economic, environmental, and social benefits. However, it is too early to be able to confidently quantify any benefits at this stage. Therefore, we instead examined the extent to which the ARCF is delivering the objectives set for it by the SIEF.

Our analysis suggests that the ARCF is satisfying all of the evaluation criteria specified for the Research Infrastructure Program. For example, the equipment purchased is leading-edge and significantly increases the research capacity of the National Resource Sciences Precinct in Perth. Furthermore, the institutions collaborating on the ARCF have developed a 'one-stop shop' approach to meeting the resources sector's growing need for increasingly detailed information about mineralisation. This approach to allocating the use of the ARCF facilities is leading the way in the creation of a more open environment for accessing research infrastructure.

While a value has not been assigned to this element of the SIEF program, ACIL Allen is confident that the benefits that will ultimately result from SIEF's investment in research infrastructure will further add to the estimated benefits of the SIEF portfolio of activities.

Promotion of Science Program

SIEF's Promotion of Science (PoS) program aims to support the creation of a nationally significant STEM workforce in Australia by helping researchers to develop their research career and the skills and experience that will enhance their career mobility.

The SIEF PoS program has been successful in helping Early Career Researchers advance their careers.

Early career researchers (ECRs) were surveyed and interviewed to obtain their views on the PoS program. Based on the information obtained from this process, the PoS program has successfully provided mentoring and general advice to ECRs; helped them to develop collaborative relationships; and improved their career mobility, and their research and non-research skills. This, in turn, has helped the majority of the ECRs to develop their research track record and further establish their research careers.

Experimental Development Program

The Experimental Development Program (EDP) was launched in 2016. The program is designed to improve the technology readiness level of the outputs of PFRA-funded research, with the aim of encouraging commercialisation and accelerating market uptake. The program is intended to address a significant gap in the current funding options available to PFRAs for progressing the commercialisation of the technologies they have developed.

As the EDP has only recently been launched, it is too early to assess the performance and benefits of the program. However, it seems likely that the EDP will complement SIEF's other programs and activities.[2]

[2] The sections on the Promotion of Science and Experimental Development programs were drafted by CSIRO.

1 INTRODUCTION

While the overall success of SIEF-funded activities, and their ultimate impact in addressing issues of national importance, are best assessed in the long term, this report seeks to develop an early conservative estimate of the potential impact and value of these activities. It does this by developing a series of case studies that probe in detail the potential benefits of a selection of SIEF's research activities; and then uses this information to develop a conservative estimate of potential benefits from the Fund.

This report estimates the potential impact and value of SIEF-funded activities.

The foundations for our estimate of the overall impact and value delivered by SIEF is based on a conservative, yet robust and defensible, estimate of a lower bound for that value based on careful analysis and CBAs for the activities supported by SIEF that have been selected as case studies, including a selection from the Research Projects Program. The following section briefly explores the rationale for using case studies.

1.1 The argument for case studies

Selecting a limited number of activities 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. The purpose of seeking representativeness is to limit the extent of bias.

In seeking representativeness it is 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. This involves arguments that:

— R&D, and innovation more generally, are inherently risky investments that can only sensibly be assessed on a portfolio basis

— 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, and clearer understanding of the most prospective areas for future research.

The case studies described in this report are likely to be representative of the full SIEF Portfolio.

Representativeness cannot involve simply looking at a random sample of SIEF-funded activities and their associated outcomes. A random sample would not be statistically relevant due to the high level of interdependency of the various samples within the Portfolio. The fact that there are joint products, spanning multiple activities with strong interactions over time, means that portfolio performance cannot be assessed or estimated by the sum of the performances of the individual activities. Careful probing of the nature of the interactions is needed to do justice to the value being created and to avoid serious bias – the very purpose in seeking representativeness.

What is needed is the presentation, with as much empirical support as possible, of a balanced understanding of the way that SIEF has enhanced Australia's overall innovation capability and the value that this brings. This requires more than an additive consideration of individual case studies – though clearly outcomes from these will provide important empirical support, and underpin the determination of SIEF's impact and value.

To ensure that the case studies can provide the best possible support for the determination of the overall impact and value of SIEF, they should:

- take into account the range of elements that can deliver value, and probe the interactions between these different elements
- include a careful consideration of benefits that are already realised, at an advanced stage of development, or identified as potential future benefits
- identify where a case study drew on previously created skills and capabilities, and the extent to which SIEF's system and culture enabled it to deliver on its objectives
- identify the collaborations entered into both with other researchers and businesses, including the financial or in-kind support that they have provided
- give consideration to the legacy of options created by the activity that is the subject of the case study. This should be supported as appropriate by examples of where those options are already being explored
- include strong Devil's Advocacy in probing the counterfactual as a basis for attributing value.

1.2 The cost benefit analysis

ACIL Allen has sought to measure relevant impacts using a cost benefit framework.

The overarching principle in the case study evaluation framework used for this report is that all relevant impacts are measured using a cost benefit analysis framework. Through that framework, ACIL Allen attempts to identify whether the attributable benefits that flow from SIEF-supported research exceed SIEF's investment in that research.

Costs are funds provided by SIEF to support production of the research outputs. Ideally, where data are available, costs should also include prior SIEF investment, and usage and adoption costs borne by the end users. For this review, time and resource constraints and commercial confidentiality issues prevented the collection of investment prior to SIEF involvement, and usage and adoption costs. Therefore, caution is required in interpreting figures on costs and associated benefit cost ratios.

There are a range of benefits that have either already been realised or are expected to be realised as a result of SIEF-supported research, including new products or services (e.g. a new drug delivery mechanism), increased productivity and efficiency (e.g. improved yield levels and mineral detection capabilities), and improved health and wellbeing (e.g. the diagnosis and prevention of obesity).

The formula for calculating the benefit cost ratio is defined as the present value of monetised benefits divided by the present value of SIEF's support for the research.

$$Benefit\ Cost\ Ratio = PV(B_t) / PV(C_t)$$

Where

$PV(B_t)$ is the present value of the benefits at time t

$PV(C_t)$ is the present value of the costs at time t

1.3 Report structure

The structure of the remainder of this report is as follows:

- Section 2 provides a brief description of five Research Projects supported by SIEF that were selected as case studies for this review. The section summarises the findings of our analysis and presents the results of the cost benefit analysis (CBA). It will also consider the other Research

Projects supported by SIEF; and discuss the potential for these projects to provide additional impact and value.[3]

— Section 3 describes the Australian Resources Characterisation Facility (ARCF) activity. As the ARCF research infrastructure being provided through SIEF funding has only recently been installed and begun operating, it is not yet possible to quantify the impact and value of the research being done with the equipment. Rather, the extent to which the ARCF activity is meeting the objectives set for the element of SIEF that supports research infrastructure has been examined. The section also briefly discusses the other Research Infrastructure activities supported by SIEF.
— Section 4 describes the SIEF Synchrotron activity. The section summarises the findings of our analysis and presents the results of the CBA. It also considers the other Special Research Program activities supported by SIEF and discusses the potential for them to provide additional impact and value.
— Section 5 reviews the performance of SIEF's Promotion of Science program.[4]
— Section 6 summarises and presents our conclusions on the overall impact and value delivered by SIEF. It draws on the results of the analysis discussed in the preceding sections.

Copies of each case study are provided in the Appendices to this report.

[3] We have also included the results for the eReefs project that was supported by SIEF. That project was examined in an earlier analysis of the impact and value of CSIRO research by ACIL Allen.

[4] The Experimental Development Program was only recently launched, and it is still too early to evaluate the program.

2 BENEFITS OF RESEARCH PROJECTS

2.1 The case studies

Five Research Projects (RP) supported by SIEF were selected as case studies for this report. The nature of these Research Projects and the benefits that they have delivered (or are expected to deliver) are summarised below.

A discussion of the estimated benefits flowing from the eReefs Research Project, which was supported by SIEF, is also included. This project was examined as part of a previous analysis of the impact and value of CSIRO's research.[5]

2.1.1 The Plant Breeding case study (RP01-006)

The Plant Breeding project aims to improve major food crop varieties in order to help feed a global population of 9 billion.

The world's population is expected to reach 9 billion by 2050. To feed this number of people, the current level of food production must be significantly increased. Societal expectations of modern agribusiness demand decreased dependence on agrichemicals and increased stewardship of land and water resources, conserving them for future generations. Increased food production will need to be achieved on existing arable land.

The Plant Breeding RP investigated two techniques to increase food production – heterosis and apomixis.

Heterosis

Plant breeding programs, together with improved management regimes, have led to steady increases in crop yields over the past five decades. However, the rate of improvement in yields has plateaued. Plant breeders have developed hybrid seed systems with increased yields over and above either of the parents (i.e. 'hybrid vigour') for corn, canola, sun flowers, sorghum, and rice. Unfortunately, hybrid vigour is not maintained through subsequent generations. The underlying molecular and cellular basis of hybrid vigour remains poorly understood.

Understanding increased yields in hybrid plants is the key to sustaining these results.

The Plant Breeding RP has provided an improved understanding of why first generation hybrids have higher yields (heterosis) than their parents, and how these yields can be maintained in subsequent generations.

The outcomes of the Plant Breeding RP's research on heterosis have also generated a significant number of collaborations:

— A new line of research has commenced in collaboration with Nuseed Ltd, which could result in end-point royalties (a levy on the harvest).

[5] An independent assessment of the economic, social and environmental impact and value of six research projects. ACIL Allen Consulting, 2016.

- The application of the heterosis work in lentils, if successful, could result in end-point royalties, shared between Nuseed, the University of Technology Sydney, and CSIRO.
- CSIRO has partnered with the Saskatchewan-based Global Institute for Food Security on grain legumes.
- CSIRO is also working with the Rice Research Institute, Sichuan Agricultural University in China to see whether the heterosis results can be applied in rice. If successful, the SIEF-funded work would completely transform the hybrid rice industry.

Apomixis

Getting plants to become apomictic could help to capture the benefits of increase yield in plant hybrids.

The RP has also sought to induce and control the expression of asexual seed formation (apomixis). Progeny of apomictic plants are clones of the mother plant. This occurs naturally in some plants, but not in most of the world's major food, feed, and fibre crops. CSIRO has led the identification of apomixis genes in *Hieracium*. The two genomic regions responsible for apomixis and seed formation have been identified in previous work undertaken in collaboration with the New Zealand Institute for Plant and Food Research Ltd. This part of the SIEF project has sought to identify the causal sequences involved. This could lead to mimicking apomixis behaviour in plants that are not naturally apomictic.

This work has resulted in a project supported by the Bill and Melinda Gates Foundation, involving a total of seven international institutions including Pioneer DuPont. Each of the partners is contributing their particular expertise.

The cost benefit analysis for the plant breeding project

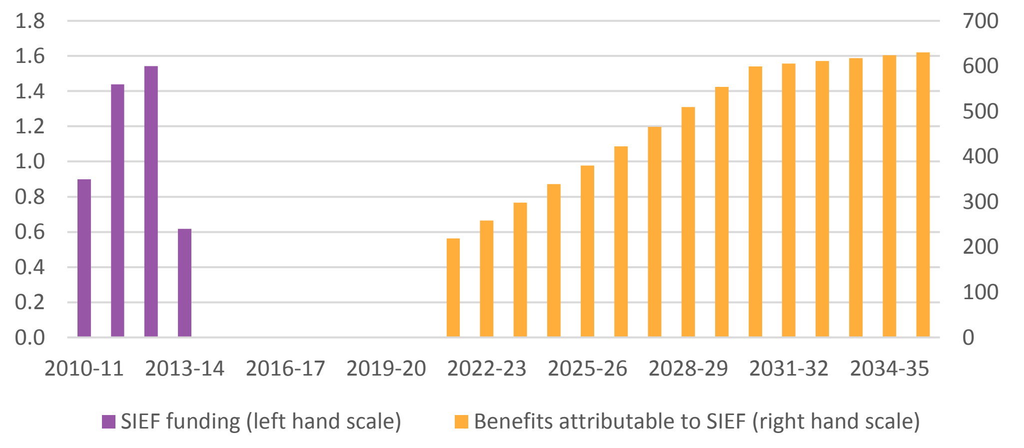
The estimated net present value of the likely benefits of the Plant Breeding project to 2035-36 is $2.82 billion.

The cost benefit analysis for the Plant Breeding RP (under a 7% real discount rate) found that:

- The present value of SIEF funding for the Plant Breeding RP is $6.2 million in 2016-17 dollars.
- The estimated present value of the benefits of the project is $2.825 billion in 2016-17 dollars.
- The estimated net present value of the project is therefore $2.819 billion in 2016-17 dollars.
- The estimated benefit cost ratio of the project is 459.5.

The costs and benefits of the Plant Breeding RP to 2035-36 are shown in **FIGURE 2.1**. Note that costs for this project are shown on the left hand axis and the benefits are shown on the right hand axis.

FIGURE 2.1 PLANT BREEDING PROJECT COSTS AND BENEFITS, BY YEAR TO 2035-36 ($M, 2016/17 DOLLARS)



SOURCE: ACIL ALLEN CONSULTING

Details of the assumptions and attributions used to arrive at these figures are included in the full case study in Appendix A.

2.1.2 The Distal Footprints case study (RP04-063)

Finding new ore bodies in Australia is difficult because they are under deep cover.

Most of the large ore deposits found in Australia have been discovered as a result of their direct surface expression. However, two thirds of the continent and the potential ore bodies contained therein, are under (often deep) cover. The signs of any ore bodies are therefore hidden. This represents both a huge opportunity and a challenge for explorers and the nation. The technical risk associated with Australian mineral exploration due to this cover is reducing investment in Australia by major mining companies. At the same time, the difficulty in obtaining capital to finance exploration, coupled with low levels of IPO activity for junior explorers, means a reduced discovery success rate.

The key to the discovery of new high grade mineral deposits is the ability to detect and recognise the distal footprints of ore bodies that are hidden deep below the surface. The Australian Academy of Science High Flyers Think Tank and UNCOVER initiative has highlighted this problem, and is encouraging exploration geoscientists to collaborate to tackle this national challenge with focussed research programs that will provide the science and the toolkit that can assist the industry boost its discovery rates.

The Distal Footprints RP provides explorers with a toolkit that facilitates the application of new techniques and technologies.

A key feature of the Distal Footprints RP is that it contributes to the stock of precompetitive research results and data on the Capricorn region.[6] This toolkit of information and test results will allow future explorers to apply new techniques and technologies to areas where mineral detection and extraction has previously been deemed too technically difficult or not cost effective enough to warrant investment based on current exploration methodologies.

In addition, a better understanding of the mineralisation could also inform decisions on how best to develop any resource that might be found.

Finally, there are also broader potential environmental benefits from improved characterisation of the Capricorn region. For example, the outputs from the Distal Footprints project have the potential to improve the way mine sites are closed, and old or unused sites are remediated. Improved characterisation provides important insights about the way mineral deposits form within a region, and how waste or hazardous materials below the earth's surface are distributed over a long term timeframe.

The cost benefit analysis for the distal footprints project

The estimated benefits cost ratio for the Distal Footprints RP is 5.4.

The cost benefit analysis of the Distal Footprints RP (under a 7% real discount rate) found that:

— The present value of SIEF funding for the project is $4.27 million in 2016-17 dollars.

— The estimated present value of the benefits of the Distal Footprints RP is $23.43 million in 2016-17 dollars.

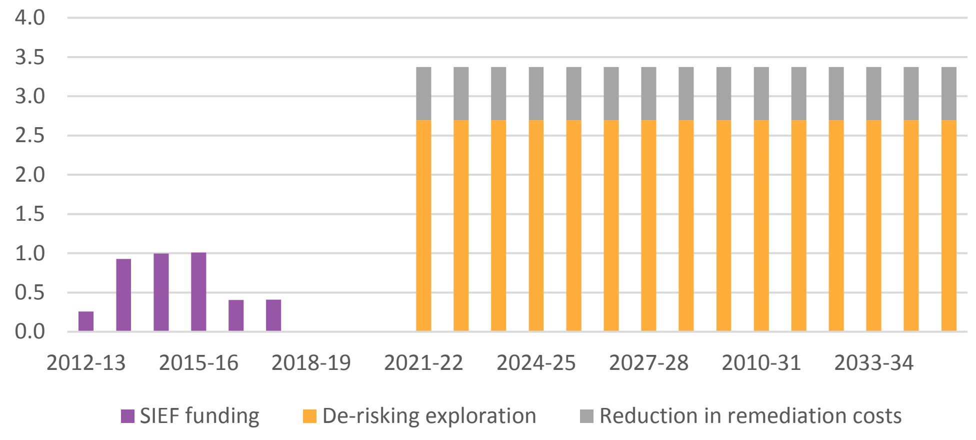
— The estimated net present value of the project is therefore $19.16 million in 2016-17 dollars.

— The benefit cost ratio of the project is 5.4.

The costs and benefits of the Distal Footprints RP to 2035-36 are shown in **Figure 2.2**. Most of the estimated benefits are assumed to flow from the distal footprints' ability to de-risk exploration.

[6] The Capricorn region is the first region in which these technologies has been applied. However, the expectation is that the same approach will be extended to other regions of Australia over time.

FIGURE 2.2 DISTAL FOOTPRINTS PROJECT COSTS AND BENEFITS, BY YEAR TO 2035-36 ($M, 2016/17 DOLLARS)



SOURCE: ACIL ALLEN CONSULTING

Details of the assumptions and attributions used to develop these estimates are included in the full case study in Appendix B.

2.1.3 The Early Nutrition case study (RP03-064)

The Early Nutrition RP has developed early life predictors for adult lifestyle conditions. It will also provide nutrition guidance for pregnant mothers.

The Early Nutrition (or EpiSCOPE) RP brought together a unique multi-disciplinary team to discover epigenetic signatures of later life metabolic traits which may be influenced by exposure to over nutrition in early life. The aim of the project was to develop early life risk predictors for adult lifestyle diseases which will help guide nutritional advice for mothers during pregnancy, and dietary recommendations for reversing the epigenetic programming and providing better health outcomes.

The project set out to understand the role of epigenetics and the epigenome in the development of human obesity and metabolic disease by conducting research in three related areas:

— Component A: Development of comprehensive epigenome and gene expression maps of adipocytes (fat cells) from obese and obese/diabetic people, in comparison to normal weight, healthy individuals.

— Component B: The impact of periconceptional maternal over-nutrition on the epigenome of adipose tissue in lambs (both in the livestock context and as a well-controlled model for human pregnancy).

— Component C: Studying the epigenomic signatures in a Human Cohort: Assessing the impact of omega-3 fatty acid supplementation in pregnancy on the epigenome, and the relationship of the epigenome to child obesity and metabolic health measures.

Reducing the future costs of obesity in humans

The Early Nutrition RP potentially assist in tailoring food industry products to assist with weight loss.

The ability to identify epigenetic differences between fat cells in obese and lean adult humans could be used both as a diagnostic and monitoring tool in the prediction and treatment of obesity, as well as providing a new understanding of the functioning of these cells and possible points of intervention. If successful, the results could also be potentially be used to tailor food industry products to assist with weight loss.

The economic costs of obesity are considerable. There are a number of studies that have assessed this cost, including:

— a study published in the Medical Journal of Australia in 2010 which estimated that the cost of obesity in Australia in 2005 was $21 billion in direct health care and direct non-health care costs, plus an additional $35.6 million in government subsidies (Colagiuri et al, 2010)

— a 2008 Access Economics report which estimated that the financial cost of obesity in 2008 was $8.3 billion. In addition, obesity also resulted in lost well-being valued at almost $50 billion

— a 2015 PwC study which estimated the cost of obesity in 2014-15 (including direct costs such as healthcare costs and indirect costs such as absenteeism, government subsidies, and foregone taxes, but excluding individual well-being losses) was $8.6 billion. The study projected $87.7 billion in additional costs due to obesity to society over ten years (2015-16 to 2024-25) if no further action is taken to slow the growth of obesity.

Livestock

The project could lead to a reduced incidence of deaths due to hypothermia in a significant proportion of the 13 million lambs born in Australia each year.

The primary purpose for studying sheep was initially as a model for human pregnancy. However, during the project the research team was able to identify genes and proteins involved in depositing brown fat in lamb foetuses.

As part of the research, ewes were over-nourished for four months before conception, then foetuses were transferred to ewes which had had normal levels of nutrition before conception. The research team found that the over nourishment of the biological parent ewes resulted in significant impacts on the organs of lambs that are involved in insulin signalling; and identified a significant impact on epigenetic chromatin markers. A paper will be submitted to Nature Communications on the results of the research[7].

The research also identified significant differences between brown and white fat in genes involved in iodine metabolism. This led to the hypothesis that dietary deficiencies in the trace elements selenium (Se) and iodine (I) might be implicated in lower than optimal levels of brown fat in new born lambs.

A better understanding of the factors influencing brown fat deposition could be important in helping to protect new born lambs. The researchers believe that increasing the deposition of brown fat in lambs could help protect new born lambs from hypothermia. If successful, this research could have considerable economic benefits, as hypothermia is the cause of death for a significant proportion of the approximately 13 million newly-born lambs which die each year.

Child obesity

The project found that there is only a relatively weak correlation between the epigenetic markers of infants and their propensity to suffer from obesity. ACIL Allen has not assigned any value to this element of the research as it is still too early to be able to predict whether it will lead to changes in medical procedures.

This project may provide a predictive test for obesity and metabolic disease in children.

However, the development of a diagnostic to predict the risk of obesity and metabolic disease in children would provide the opportunity for early detection of at risk children and subsequent intervention. Such a test could generate significant benefits. Indeed, research (undertaken with support from the NSW Office of Health & Medical Research Innovation program) suggested that Australians would be willing to pay up to $250 to obtain a predictive test for obesity and other health issues for children.

The cost benefit analysis for the early nutrition project

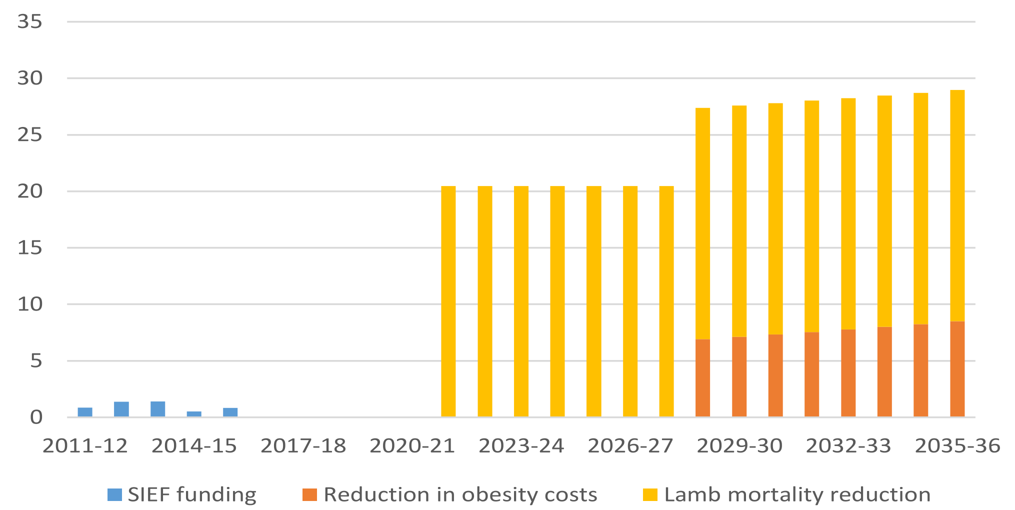
Based on conservative valuations, the net present value of the Early Nutrition RP has been estimated at $422 million.

The key results of the cost benefit analysis for the early nutrition case study (based on a 7% real discount rate) are:

— The present value of SIEF funding for the project is $6.23 million in 2016-17 dollars.[8]
— The present value of project benefits is estimated to be just over $428.2 million in 2016-17 dollars.
— The net present value of the project is therefore estimated to be $422 million in 2016-17 dollars.
— This means that the estimated benefit cost ratio of the Early Nutrition RP is 69.1.
— The costs and estimated benefits that flow from the different potential applications of the early nutrition project out to 2035-36 are shown in **Figure 2.3**.

7 This kind of research on humans would not be possible for ethical reasons.
8 Throughout this document the term “SIEF funding” refers to support provided by SIEF and does not take into account any other cash or in-kind investment by others.

FIGURE 2.3 EARLY NUTRITION CASE STUDY COSTS AND BENEFITS BY YEAR TO 2035-36 ($M, 2016-17 DOLLARS)



SOURCE: ACIL ALLEN

The majority of these very significant benefits result from the commercialisation of the test for new born infants. Details of the assumptions and attributions used to arrive at these figures are included in the full case study in Appendix C.

2.1.4 The Energy Waste case study (RP02-035)

The initial objective of the Energy Waste RP was to develop new materials and processes for the capture and utilisation of carbon dioxide (CO_2). The research team conducted research that sought to:

— develop new Metal-Organic Framework materials (MOFs) that could be used to separate CO_2 efficiently and cost-effectively from the exhaust gas of a coal or gas burning power station

— develop technologies that can convert captured CO_2 into products with commercial value that could help improve the economic viability of carbon capture

— scale up the production of the MOFs developed by the research team.

The Energy Waste RP has produced outputs relevant to carbon dioxide capture, and in five other areas with commercial potential.

While the research team was able to identify a number of potential candidate MOFs, the current policy settings for reducing greenhouse gas emissions mean that the CO_2 capture process using MOFs remains uneconomic. However, the research did produce some important outputs and the team is currently pursuing five other potential commercialisation opportunities:

— Anti-corrosive coatings

— Toxic gas filter

— Breathing apparatus

— Controlled release of enzymes

— Enhanced plastic piping.

Anti-corrosive coatings

Current anti-corrosive coatings are based on chromates, which have a number of negative health implications. The new MOF based approach to anti-corrosive coatings would avoid these risks. The product is being developed in partnership with a multinational aeronautical company. Under the terms of the agreement, CSIRO is entitled to develop anticorrosive coatings in other areas should it wish to.

Toxic gas filters

While the MOFs currently are designed to capture CO_2, the size and chemistry of the pores in the MOFs can be varied to target the capture of differing chemicals. CSIRO has been working with the Defence Department since February 2016 to develop a prototype filter that could meet the

ADF's capability needs for respiratory protection. Following successful completion of the proof of concept phase of the project, Defence has provided funding of $3.2 million to enable CSIRO to incorporate MOFs into a filter canister for use with the in-service respirator. This work is initially aimed at supplying the 40,000 front line soldiers of the defence force. In due course the technology could be extended to first responders and other allies.

Breathing apparatus

The use of MOFs can ensure that a breathing apparatus can remain effective for a longer period of time, and in a safer fashion. This will be a civilian application of the respirator filters initially developed for the defence force.

Controlled release of enzymes

Encasing enzymes in a purpose designed MOF results in their being stabilised when exposed to heat. The MOF coating is porous, so it is possible to have a steady release of enzymes over time. This technology is being developed for a non-medical application (in order to get a faster route to impact). The application is global. The work is being done in partnership with a large multinational firm.

Enhanced plastic piping

The MOF technology is expected to enable the production of a premium plastic product that would enable both the production of thinner pipes (i.e. requiring less material for the same strength) or larger pipes (that did not have weight problems) The development is being done in partnership with an Australian chemical company.

The cost benefit analysis for the energy waste project

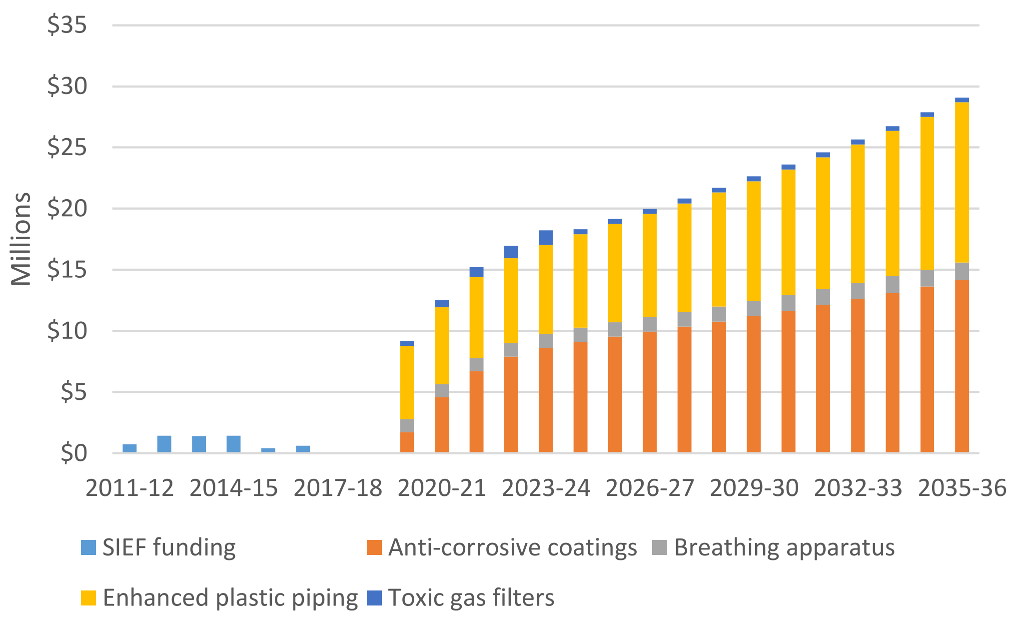
The Energy Waste RP is expected to realise significant economic and environmental benefits. The estimated benefit cost ratio is 20.8.

The key results of the cost benefit analysis for the Energy Waste RP (under a 7% real discount rate) are:

— The present value of SIEF funding for the Energy Waste RP is $7.3 million in 2016-17 dollars.
— The estimated present value of the benefits of project is $151.6 million in 2016-17 dollars.
— The estimated net present value of the project is therefore just under $144.3 million in 2016-17 dollars.
— Therefore the estimated benefit cost ratio of the project is almost 20.8.

The costs and estimated benefits that flow from the different potential applications of the Energy Waste RP out to 2035-36 are shown in **Figure 2.4**.

FIGURE 2.4 ENERGY WASTE PROJECT COSTS AND BENEFITS, BY YEAR TO 2035-36 ($M, 2016/17 DOLLARS)



SOURCE: ACIL ALLEN CONSULTING

Details of the assumptions and attributions used to arrive at these figures are included in the full case study in Appendix D.

2.1.5 The RAFT case study (RP02-051)

The RAFT RP has sought to apply this CSIRO technology to the detection and treatment of cancer.

This Research Project has sought to apply CSIRO's Reversible Addition Fragmentation chain Transfer (RAFT) technology to:

— develop polymer coatings that modify the surface of implantable materials such as those used by Cochlear for its hearing implants

— join (conjugate) an antibody fragment to one or more cytotoxic drugs which can be released to treat cancer

— provide proof of concept for a new test (immunohistochemistry assay) for the presence of antigens in tissue sections containing tumour cells

— develop a new drug delivery mechanism for therapeutic drugs.

Each of these elements of the project are briefly discussed below (more detail is available in the full case study in Appendix E).

Surface Modification

This element of the project (done in collaboration with Cochlear) sought to develop polymer coatings that modify the surface of implantable materials to enhance biocompatibility for biomedical device companies seeking a new technology to enhance existing or new products. While the research has produced some interesting and useful results, it is unlikely to be applied directly by Cochlear at this stage. However, the knowledge gained from this work has resulted in Cochlear changing the direction of some of its research, which has saved the company millions of dollars.

Conjugation of bioactives

The objective of this research was to develop a polymeric scaffold for targeted drug delivery through linking (conjugation) of both a cytotoxic small molecule drug and an antibody fragment. If successful, this technology would be applicable to the management of breast, prostate, colorectal, lung, and other cancers.

A range of polymers has been developed that meet all the requirements for use in a biological setting. Cytotoxic drug-loaded polymers have been prepared with an appropriate functional group for conjugation to antibody fragments. The cytotoxic drugs are attached to the polymer via cleavable linkers such that the free cytotoxic drug can be released at the site of action. Absorption, distribution, metabolism, excretion, and toxicity studies have been undertaken in animal models.

The results show that drug-loaded polymer-antibody fragment conjugates are effective in reducing tumour burden and keeping the tumours negligible beyond completion of the injection regimen. This research has shown proof-of-concept preclinical studies, which will facilitate the engagement of pharmaceutical and biotechnology companies to take the technology into clinical development.

Test for the presence of antigens

This work, with Planet Innovation Ltd, involves a proof of concept study to assess the use of RAFT polymers for the development of immunohistochemistry (IHC) assays. The polymer acts as a carrier or scaffold for a bioactive. IHC is an assay that detects the presence of proteins in biological tissues. A thin tissue section of tumour can be examined to detect antigens in areas of tissue containing tumour cells, such as proteins that are known to be overexpressed at the surface of cancer cells. The areas that contain the protein that is being detected are stained brown.

This work has the potential to provide improvement in testing for pathology laboratories and clinicians, providing significant cost savings to the laboratories and more accurate testing for consumers.

Delivery of therapeutic agents

The objective of this research was to develop a technology for the preparation of polymers that act as a prodrug for the delivery of therapeutic agents. If successful, the results of this research would provide new polymer reagents for transfection.

This leading-edge research has the potential to provide targeted delivery of anti-cancer drugs.

This project involves delivery of a polymeric-drug conjugate that carries an antimicrobial drug (ciprofloxacin) as a prodrug monomer, copolymerised into a hydrophilic polymer carrier. This prodrug pulmonary delivery vehicle construct is delivered via aerosol into the lung. Other studies have been performed on these ciprofloxacin-containing polymers in order to understand and probe the toxicity and antimicrobial efficacy of the different polymeric structures and the different linkers installed to release ciprofloxacin. These studies have demonstrated that these polymers have a very good antimicrobial efficacy across a number of structures. A provisional patent has been published.

The path to market is less well defined for this application; and more discussions are required with potential commercial partners (primarily pharmaceutical companies) to clarify potential adoption timeframes.

The cost benefit analysis for the RAFT project

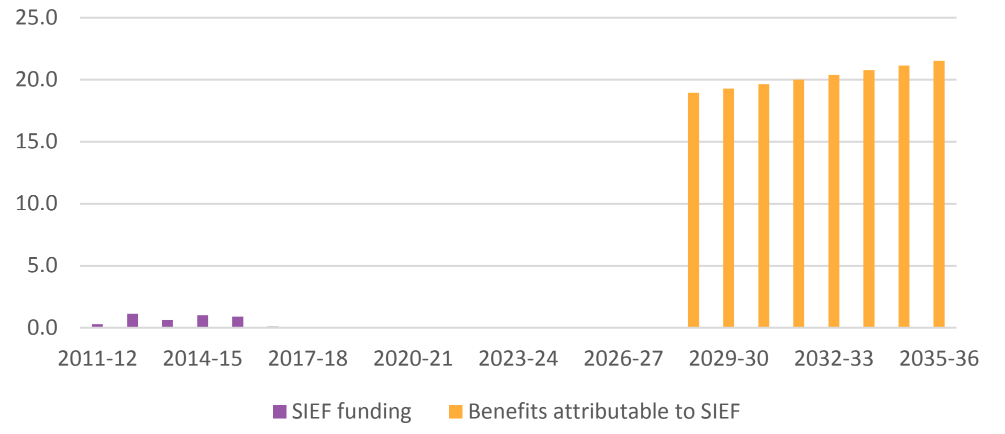
The RAFT RP is anticipated to provide significant economic and health benefits for Australians.

The results of the cost benefit analysis for the RAFT RP (under a 7% real discount rate) found that:

— The present value of SIEF funding for the project is $4.80 million in 2016-17 dollars.
— The estimated present value of the RAFT project's benefits is $53.24 million in 2016-17 dollars.
— The estimated net present value of the project is therefore $48.44 million in 2016-17 dollars.
— The benefit cost ratio of the RAFT RP is 11.08.

The costs and estimated benefits of the project over the period to 2035-36 are shown in **Figure 2.5**.

FIGURE 2.5 RAFT PROJECT COSTS AND BENEFITS, BY YEAR TO 2035-36 ($M, 2016/17 DOLLARS)



SOURCE: ACIL ALLEN CONSULTING

Details of the assumptions and attributions used to arrive at these figures are included in the full case study in Appendix E.

2.2 The benefits of the SIEF Research Projects

2.2.1 The research activities selected as case studies

The estimated benefit cost ratio for the six Research Projects (including eREEFs) is 105.7.

The preceding sections presented the cost benefit analysis of five Research Project activities supported by SIEF that were selected as case studies. The aggregated results of the CBAs for these case studies (based on a 7% real discount rate) found that:

— The present value of SIEF funding for the five Research Project activities plus eReefs is $33.05 million in 2016-17 dollars.

— The estimated present value of the benefits of the Research Projects is $3.494 billion in 2016-17 dollars.

— The estimated net present value of the Research Projects is therefore $3.461 billion in 2016-17 dollars.

— Based on the above numbers, the overall benefit-cost ratio of the six Research Projects is estimated to be 105.7.

The estimated benefits of the six Research Projects are very substantial. Furthermore, the benefits were estimated using highly conservative assumptions. In addition, there were a number of potential benefits associated with the case studies which were unable to quantified, either because it is still too early to confidently quantify the benefits or because of confidentiality provisions surrounding the commercialisation of some of the case study outputs. In other words, there is a valid argument that a number of the case studies examined could be attributed with substantially higher benefits than the initial estimates listed above.

When both the nature of the assumptions used and some of the dimensions of value that were not able to quantified are considered, the above estimate of benefits could be regarded as a lower bound and, consequently, that there is considerable potential upside to the estimated benefits.

Given that a number of the case studies are still only at the beginning of their path towards potential commercialisation, it is possible that some of the anticipated benefits may not eventuate or may only eventuate further in the future. However, despite this uncertainty, ACIL Allen is extremely confident that given the many paths towards delivering potential benefits being actively explored, the eventual benefits will easily exceed the costs of the six case studies. Indeed, it is highly probably that benefits from just these six projects will comfortably exceed the total cost of the SIEF Portfolio.

KEY FINDING 1 THE BENEFITS OF SIEF RESEARCH PROJECTS

ACIL Allen believes it is highly probably that the benefits from the six RP case studies alone will comfortably exceed the total cost of the SIEF Portfolio.

2.2.2 The other SIEF supported research projects

The examination of the impact and value from the five SIEF RP activities selected as case studies estimated that the benefits of these case studies would exceed their costs by a very wide margin. However, as this finding is based only a small sub-set of the 17 RP activities supported by SIEF, it is likely to underestimate the benefits that the full program of RP activities could deliver.

Time and resources do not permit us to analyse the other 12 RP activities in detail. However, a previous project conducted by ACIL Allen examined the impact and value of six CSIRO research projects, one of which was the SIEF-supported eReefs RP.[9] The results of that analysis of the eReefs RP are discussed below.

The eReefs RP

The eReefs research will significantly transform Australia's ability to manage and protect the Great Barrier Reef.

The eReefs case study describes the economic, environmental, and social benefits arising from CSIRO's and its partners' research on the Great Barrier Reef (the Reef). The analysis concluded that the eReefs research will significantly transform Australia's ability to manage and protect the Great Barrier Reef, assisting in its long-term preservation. It has delivered powerful real-time visualisation and reporting tools that will provide users with real-time information about the condition of the Reef.

The eReefs models are being used by the Great Barrier Reef Marine Park Authority and the Queensland government to aid decision making, and by the Bureau of Meteorology to deliver remote sensing products based on CSIRO's algorithms.

The case studies described in this report are likely to be representative of the full SIEF Portfolio.

How representative are the case studies?

It is important to assess the extent to which the five Research Project case studies are representative (or not) of the full portfolio of research supported by SIEF. It is possible to compare the performance of the five RP activities selected as case studies against the remaining 12 RP activities that were not examined in detail. The results are shown in **Table 2.1**.

9 Six case studies to demonstrate the impact and value of CSIRO research, ACIL Allen, 2016

TABLE 2.1 COMPARISON BETWEEN CASE STUDIES AND REMAINDER OF RESEARCH PROJECTS

Indicator	Case Study Projects	Other RP activities
Number of publications	105	141
Number of patents	15 (this includes 14 patents reported by the RAFT project after the cut-off date for the original reporting period)	21
Proportion of financial contribution to project provided by collaborators	63%	60%
Percentage of RP activities involving more than one organisation	80%	92%
Number of RPs that have received additional funding to further develop the outputs of their SIEF project	4 (out of 5) (this includes the Gates Foundation funding for the Plant Breeding project which was reported after the cut-off date for the original reporting period)	5 (out of 12)

Notes: 1. These were the only KPIs where performance of the Research Project case studies could be compared to the performance of the remainder of the Research Projects. 2. The information in the table is based on reporting from SIEF-supported research projects.
SOURCE: CSIRO

The information in **Table 2.1** suggests that the SIEF RP activities selected as case studies are broadly similar in nature to the 'other Research Projects', at least in terms of the KPIs listed. While this clearly does not provide any guarantees that the 'other RP activities' will deliver a similar level of benefits, it does provide a degree of confidence that they might do so. The number of patents generated by the 'other RP activities' particularly supports this view.

3 BENEFITS OF RESEARCH INFRASTRUCTURE PROJECTS

The objective of SIEF's Research Infrastructure program is to support the creation or enhancement of nationally significant research facilities or equipment. To date SIEF has invested $40.4 million in three Research Infrastructure activities. They are the:

— Advanced Resource Characterisation Facility (ARCF) in Perth
— Biomedical Materials Translational Facility (BMTF) in Clayton
— National Agricultural & Environmental Sciences Precinct (NAESP) in Canberra.

3.1 The Advanced Resource Characterisation Facility (ARCF)

SIEF has provided a $12.4 million grant as part of the 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 ACRF will provide an approach to minerals exploration and processing unmatched anywhere in the world.

The ARCF provides a global hub for metre to atomic scale analyses through an advanced workflow involving the measurement and interpretation of multi-scale compositional analyses for the research community, industry, and government geoscience agencies. The SIEF funding has enabled the purchase and installation of three items of equipment at three sites in Perth. Access arrangements for the Foundation Research Partners (the University of Western Australia (UWA), CSIRO, and Curtin University) are common across the three sites. The new equipment will be used primarily to conduct research to support minerals exploration and processing.[10] The objectives of the ARCF project are to:

— purchase, install (including refurbishment of sites to house the equipment), operate, and provide access to the following research infrastructure assets:
— the Maia Mapper hosted by CSIRO (for core-scale chemical mapping)
— the NanoSIMS hosted by UWA (for sub-micron elemental and isotopic mapping)
— the Geoscience Atom Probe hosted by Curtin (for sub nanoscale characterisation)
— increase effective collaboration and optimise equipment utilisation, minimise duplication, encourage complementary work, and attract a further cohort of world class researchers to the State within a major national research precinct (the National Resource Sciences Precinct).

Combined with the partners' existing equipment, and data management, processing, and integration made possible by the Pawsey Centre supercomputer, the ARCF will provide a multiscale approach to the characterisation of geological materials unmatched anywhere in the world.

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10 The leading-edge nature of the equipment is already attracting attention from researchers in other fields as well as from private sector firms.

Given that the SIEF-funded research infrastructure has only recently become operational, it is too early to be able to identify any outputs from the users' research. However, there are a number of interesting projects already underway. The primary aim of the researchers at present is to continue to build the profile of the ARCF by publishing their results in high impact journals.

There is certainly the potential for the research being undertaken to deliver very significant impact. For example, one project involves studying zircon crystals to identify where minerals have migrated to within the crystal. A better understanding of where minerals are located and how they might migrate over time can help inform decisions about how to extract those minerals. This could lead to potential energy savings in the extraction process. Given that some 5% of global energy consumption is used to extract minerals, the potential benefits from even a small reduction in energy consumption in this area could be considerable.

Improved characterisation of mineral behaviour could contribute to improving mine site remediation.

There also may be environmental benefits from the research being conducted. For example, improved characterisation of the behaviour of minerals could play a role in improving the remediation of old mine sites, and potentially reduce the economic burden of environmental damage associated with mining.

Finally, there may be social benefits from the research being carried out. Possible benefits include improved employment opportunities associated with the discovery of new mineral resources or health benefits associated with the biomedical research being conducted to test drug and chemical delivery mechanisms in biological samples.[11]

Given that it is too early to assess the impact of the research, the extent to which the ARCF is delivering the objectives set for it by SIEF has been examined instead.

The Deed of Gift between CSIRO and SIEF identified a number of Special Purpose Areas which may attract investment from the Fund. SIEF provides the following definition in relation to Landmark Research Infrastructure activities that it may support:

> *Landmark Research Infrastructure comprises the creation or development of nationally significant facilities for the conduct of research. This includes investment into national scale scientific equipment and special purpose facilities for the conduct of scientific research.*[12]

The SIEF guidelines list four evaluation criteria, namely that supported Research Infrastructure activities should:

1. Address infrastructure priorities for developing national research precincts
2. Demonstrate high benefits and effective use of resources
3. Utilise capital funding to efficiently address infrastructure needs
4. Demonstrate they achieve established standards in implementation and management.

The following content examines the extent to which the ARCF activity outcomes to date have delivered against all four of these evaluation criteria.

Addressing the infrastructure needs of national research precincts

ARCF equipment can characterise samples from drill cores down to atomic scale.

The three items of equipment purchased can deal with characterisation of samples from drill cores to the atomic scale. The suite of instruments run by the ARCF allows the research partners to generate a workflow of minerals research activity that can progress research outcomes gained from the use of one instrument to further research on another instrument. It allows for a high degree of collaboration and synchronisation in the research process by bringing the research together in a 'one stop shop'.

ACIL Allen has no doubt that the research infrastructure funded by SIEF will deliver significant and valuable capability to the National Resource Sciences Precinct in Perth; and that the research that will be possible as a result of this infrastructure aligns well with the existing research priorities of the partners in the activity.

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11 Ibid.

12 Research Infrastructure - Key Principles and Funding Guidelines - available at http://www.sief.org.au/FundingActivities/Research-Infrastructure.html

This view is supported by the fact that the Atom Probe operated by Curtin University is the only one of eighty worldwide to be dedicated solely to geosciences research. The NanoSIMS equipment is one of only forty such machines in the world. Once operational, the laboratory-scale Maia Mapper will be able to create micro-scale elemental maps of 2 centimetre by 1 centimetre rock samples in about six hours, providing an enormous increase in sensitivity, detection limit and spatial resolution over conventional systems.

Co-investment by partners is almost twice SIEF funding.

The level of co-investment by the ARCF partners is almost twice the SIEF funding. This considerable investment provides a good indication of the importance that the partners place on having access to the high-end equipment funded by SIEF.

Demonstrating high benefits and effective use of resources

As noted above, it is too soon in the research timeline to be able to confidently predict the scale of the benefits associated with the ARCF activity. However, there are good indications that the research being conducted with the facilities has the potential to deliver significant economic, environmental, and social benefits.

The addition of these items of equipment has provided significant additional capability to the existing research infrastructure. For example, the NanoSIMS facility at UWA has significantly boosted the capability of the Centre for Microscopy, Characterisation, and Analysis at that university. Similarly, the Geoscience Atom Probe complements the existing research equipment at the Department of Applied Geology at Curtin University.

Efficient use of capital funding to address infrastructure needs

The SIEF investment in the ARCF research infrastructure has delivered state-of-the-art technology that will significantly increase the research capability within the National Resource Sciences Precinct. The organisations collaborating in the ARCF activity all agreed that no other source of funding could have supported the acquisition of the equipment to which the ARCF now has access. They are also confident that the capabilities created by this suite of equipment are world-leading.

The fact that the co-investment by the partners in this project is almost twice that of SIEF illustrates that the Fund was able to unlock considerable additional investment through the funding it provided for this activity.

The ARCF equipment has proved to be instrumental in helping to attract high profile overseas researchers to Perth. The NanoSIMS equipment has already been used by seven overseas projects during 2016. As a result, the UWA has hosted researchers from the UK, USA, Saudi Arabia, Germany, and China.

The ARCF activity has also proved to be extremely successful in encouraging research collaborations. The NanoSIMS facility alone has led to collaborations with thirteen Australian universities and six overseas research organisations.

Achieving established standards in implementation and management

There is little doubt that the participating organisations have worked together very effectively to prepare the facilities to house the equipment, and to purchase and install the research infrastructure.

ARCF is providing a one-stop shop approach to meeting the needs of the resources sector.

The research partners in the ARCF activity have also collaborated to develop a regime for allocating access to the research infrastructure that is common across all three instruments. This ‘one-stop shop’ approach to meeting the resources sector’s growing need for increasingly detailed information about mineralisation is an excellent outcome. The research partners believe that they are in the vanguard of a broader move towards the creation of a more open environment for accessing research infrastructure.

3.2 Other Research Infrastructure Projects

The other two Research Infrastructure activities supported by SIEF are briefly described below. The impact and value of these two activities have not been quantified.

3.2.1 Biomedical Materials Translational Facility

The Biomedical Materials Translational Facility (BMTF) is led by Monash University and CSIRO, and is based at the Monash Health Translation Precinct (MHTP) in Melbourne with partners MIMR-PHI and ANSTO.[13]

The SIEF investment has leveraged a $21.5 million contribution from CSIRO and Monash, and further investment from emerging industry partners. The work of the BMTF has a particular focus on the '3Ds' (delivery, diagnostics, and devices) as applied to the diagnosis and treatment of key chronic diseases such as cardiovascular disease, cancer, and ophthalmic diseases.

3.2.2 National Agricultural & Environmental Sciences Precinct

The National Agricultural & Environmental Sciences Precinct (NAESP) is a globally significant research and innovation sciences precinct in Canberra. SIEF has invested in developing the Centre for Genomics, Metabolomics, and Bioinformatics. The Centre aims to enhance the rate at which gene discoveries can be applied in areas such as crops and environmental management. SIEF has also invested in a new life sciences building on the CSIRO Black Mountain campus. The funding is designed to ensure that the laboratory's microscopy and analytical facilities can support the delivery of outstanding research.

3.3 The benefits of SIEF's support of the Research Infrastructure (RI) program

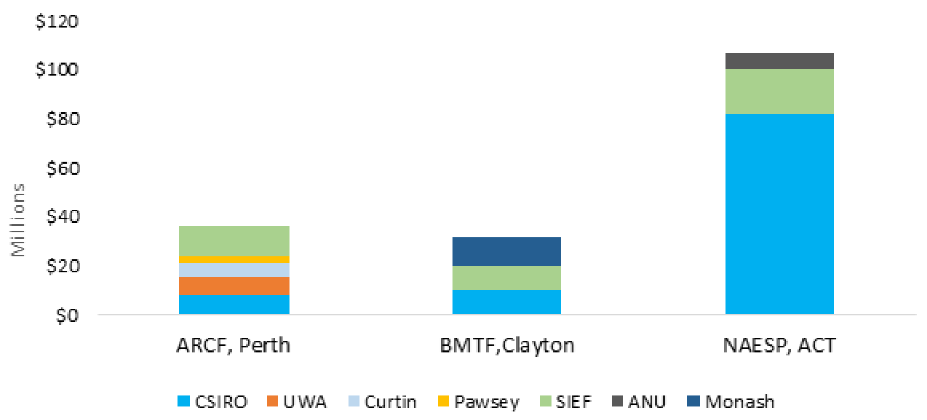
Stimulating co-investment

The investment by SIEF of $40.4 million in these three research infrastructure projects stimulated a co-investment of $133.8 million from 7 other organisations (5 universities, CSIRO and the Pawsey Centre). In other words, the SIEF funding mobilised from other organisations more than three-and-a-quarter times SIEF's investment.

SIEF investment of $40.4m in the three research infrastructure has stimulated co-investment of $133.8m.

Figure 3.1 shows the relative investments by different organisations in the three SIEF RI activities.

FIGURE 3.1 INVESTMENT IN RESEARCH INFRASTRUCTURE PROJECTS



SOURCE: CSIRO

[13] The organisation formed by the merger of the Monash Institute of Medical Research (MIMR) and Prince Henry's Institute (PHI) is known as the Hudson Institute of Medical Research. The Institute is one of Australia's top medical research institutes, specialising in driving innovative, cutting-edge research towards improved prevention, diagnosis, and treatments for our greatest health challenges.

Enhancing capability and capacity

The research infrastructure funded by SIEF will deliver significant and valuable capability to the National Sciences Precincts in Perth, Clayton, and Canberra. The equipment that has been provided through the support of SIEF is leading-edge, and will help ensure that the research at those facilities is world-leading.

The mechanisms that are being put in place to manage access to these items of equipment should ensure that their capabilities are exploited to the fullest extent possible; and that the research that will be possible as a result of this infrastructure aligns well with the existing research priorities of the partners in the project.

Encouraging collaboration

All three of the research infrastructure activities have multiple partners. The research infrastructure activities have all provided existing research hubs with excellent infrastructure that will support leading-edge research in areas of national priority (resources, health, and agriculture) for many years to come.

The high quality of the equipment being installed under this SIEF program is likely to attract researchers from across the country. The leading-edge nature of the facilities is also likely to attract interest from international researchers and firms.

Other benefits

The activity selected as the case study for this element of the SIEF program has yet to reach the point where it is possible to begin to explore the nature and scale of potential benefits. Similarly, there is no information yet on the benefits that might ultimately flow from the other Research Infrastructure activities. However, the level of utilisation of the equipment, the national and international attention it is garnering, and the interest that is already being shown by industry strongly suggest that it will not be very long before potential impact and value benefits can begin to be assessed.

While a value has not been assigned to this element of the SIEF program, ACIL Allen is confident that the benefits that will ultimately result from this investment by SIEF will only further add to the estimated benefits from the other elements of the SIEF portfolio of activities.

4 BENEFITS OF SPECIAL RESEARCH PROGRAM

From time to time SIEF may fund activities that align with the purpose and strategic objectives of SIEF, but which fall outside the scope of support which SIEF provides for Research Projects, Research Infrastructure, or Promotion of Science. If support is deemed to be warranted, then these activities can be funded under the SIEF Special Research Program (SRP). The Special Research Program supports activities that are identified as subject to funding gaps in the National Innovation System.

To date SIEF has provided funding for two such activities, namely:

— The Australian Square Kilometre Array Pathfinder (ASKAP) in Western Australia.

— The Australian Synchrotron in Clayton, Victoria.

The Australian Synchrotron was selected as one of the case studies for this review.

4.1 The Synchrotron case study

Synchrotron science has revolutionised experimental techniques since the late 1970s. For many years, Australian researchers have used overseas synchrotron, notably in France, Japan, and the USA. However, with demand for beam time often exceeding availability, and the cost of international travel, it became clear in the late 1990s that for Australia to remain internationally competitive in this field of research, Australian researchers needed a national facility.

In June 2001, the Victorian Government announced its decision to build a national synchrotron facility. Construction of the Australian Synchrotron began in 2003. However, synchrotrons require beamlines to be set up with research instruments. In January 2004, the then Victorian Minister for Innovation announced that the University of Melbourne, Monash University, Australian Nuclear Science and Technology Organisation (ANSTO), and CSIRO would each provide $5 million towards nine initial beamlines planned for the Australian Synchrotron.

The SIEF Synchrotron Science SRP activities ranged across a number of sectors, with the majority of projects relating to minerals, health, manufacturing, and energy.

In June 2007, the Commonwealth and Victorian Governments agreed that each would provide $50 million in operating funds for the period to June 2012. The New Zealand Government also committed to contribute operating funds. Synchrotron operations commenced in July 2007. It is now serving the needs of the wider research community, providing a platform for leading-edge research and development across a wide spectrum of science and technology, from medicine to manufacturing.

With the imminent expiry of the funding arrangements mentioned above, a funding package was required ($100 million over 4 years) to provide for the running costs of the Synchrotron. CSIRO, acting on behalf of the Commonwealth Publicly Funded Research Agencies (PFRAs), coordinated a response to an invitation by SIEF to submit a proposal for a four-year Special Research Program (SRP) for PFRA scientists to access the synchrotron for research that aligned with SIEF's Strategic Objectives. Five PFRAs participated in the proposal, with CSIRO the nominated Administering Organisation. The five Agencies were:

- The Australian Nuclear Science and Technology Organisation (ANSTO)
- CSIRO
- The Defence Science and Technology Organisation (now Defence Science and Technology Group)
- Geoscience Australia
- The National Measurement Institute.

In the four-year period 2012-16, SIEF funding has supported 243 synchrotron research projects conducted by PFRAs. All but thirteen of these projects have been led by CSIRO. The majority of CSIRO-led projects have involved research collaboration partners from universities, medical research institutes, and other research organisations. PFRA researchers have also participated in many other synchrotron projects led by other collaboration partners.

The SIEF Synchrotron Science SRP activities ranged across a number of sectors, with the majority of projects relating to minerals, health, manufacturing, and energy. From the projects supported by SIEF, three have been selected based on the likely significance of their impacts.

Minerals industry application of synchrotron research

CSIRO and the Australian Synchrotron have demonstrated that gold in leaves of desert plants are an indication of deeply buried ore bodies.

CSIRO and the Australian Synchrotron have used the Maia detector for X-ray Fluorescence Microscopy (XFM). The detector is an important piece of equipment for the detailed chemical mapping and analysis of mineral samples. The Maia detector was instrumental in the discovery that some species of desert eucalypts and acacias concentrate traces of gold in their leaves as a by-product of their deep-rooted search for water and nutrients in hostile desert environments.

Australia has an ancient landscape, with much of its geology covered by deep layers of eroded material. Mineral exploration in many parts of Australia is made more difficult and expensive because of the nature of this deep cover. By demonstrating that nano-particles of gold in leaves of desert plants are an indication of deeply buried ore bodies, the CSIRO team has used the synchrotron to open a whole new field of bio-geological mineral exploration technologies with which new major ore bodies may be discovered.

Medical application of synchrotron research

Synchrotrons play an important role in the study of biochemicals and the development of new pharmaceuticals. With the help of CSIRO's Collaborative Crystallisation Centre, the Cooperative Research Centre for Cancer Therapeutics (CRC-CTx) has developed a compound that binds to and inhibits arginine methlytransferase 5 (PRMT5) proteins which are implicated in both cancer and non-cancer blood disorders affecting millions of people.

Synchrotrons play a key role in understanding the structure of proteins and enzymes.

This compound is now licenced, through Australian company Bionomics Ltd, to MSD, an Australian arm of the multinational drug company Merck. High levels of PRMT5 are found in mantle cell lymphoma, chronic lymphocytic leukaemia, melanomas, and lung and breast cancers, and are linked to low survival rates. In addition to applications for cancer, PRMT5 inhibitors switch on important genes in the development of blood, which could provide disease-modifying treatment options for patients with blood disorders like sickle cell disease and beta thalassemia.

Primary industry and manufacturing application of synchrotron research

A team from the CSIRO's Food and Nutrition group has used the Australian Synchrotron to examine the nanostructure of casein micelles, a protein structure found within components of cow's milk. This research was conducted in partnership with the Victorian Government Department of Economic Development, Jobs, Transport, and Resources.

Synchrotron studies are helping Australian dairy exporters.

Investigating micellar behaviour at the nanoscale through the Australian Synchrotron was crucial to the research team's efforts to devise improvements for Australia's milk processing industry. By better understanding micelle formation in cow's milk, researchers can improve the way milk is processed into different products and stored to maintain quality. This is particularly important to support the milk export industry that exports products such as milk powder and cheese to growing Asian markets.

4.1.1 Benefits to Australia

The Australian Synchrotron is a tool that facilitates research. The synchrotron component is usually only one element of this research. Research projects that have used the synchrotron as part of their research are likely to generate outcomes over time. The main beneficiaries are expected to be industry and the general public.

SIEF-supported synchrotron projects have the potential to provide a wide range of economic, social, and environmental benefits. Because there have been a large number of these projects, it has not been possible to undertake a comprehensive analysis of the outcomes. Furthermore, it is still too early to be able to judge the eventual outcomes for many of the projects undertaken.

However the potential benefits from just the three examples examined in this case study are considerable:

— Assessment of gold in eucalypt leaves saves the cost and the time involved in drilling unnecessary exploration wells. More than $740 million was spent in the search for gold in Australia in 2012. If this research results in even a small improvement in exploration cost efficiency, or contribution to the development of new mines, the benefits would be significant.

— The discovery of the new pharmaceutical for treating blood disorders has resulted in an initial payment from MSD to Bionomics in excess of $21 million and potential payments are expected to exceed $700 million. The majority of revenues will be returned to CTx and its Australian research partners. There will also be additional funded collaboration between MSD and CTx on blood disorders. ACIL Allen has not sought to calculate the value of the potential human health benefits (both social and economic).

— Understanding the nanostructure of casein micelles has significant potential benefits for Australia's $13 billion dairy farm, manufacturing, and export industry The Australian dairy industry directly employs 43,000 Australians on farms and in factories, while more than 100,000 Australians are indirectly employed in related service industries. The results of this research will facilitate increased production, employment, and exports of milk-based products.

4.1.2 Cost benefit analysis

The estimated net present value of benefits from three Synchrotron SRP activities is $799.3 million.

The cost benefit analysis of the Synchrotron SRP activity (based on a 7% real discount rate) found that:

— The present value of SIEF funding for the activity is $11.88 million in 2016-17 dollars.

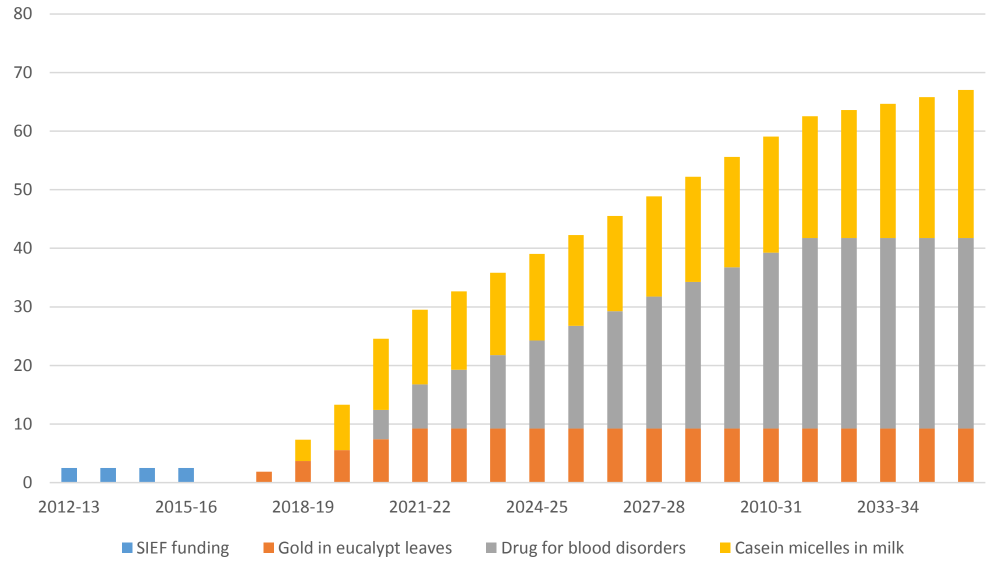
— The estimated present value of the benefits from the synchrotron activity is $811.2 million in 2016-17 dollars.

— The estimated net present value of the project is therefore $799.3 million in 2016-17 dollars.

— The above information can be used to derive a benefit cost ratio for the SRP synchrotron activity of 68.3.

The time profile of the costs and potential benefits associated the synchrotron activity to 2035-36 are shown in **Figure 4.1**.

FIGURE 4.1 PROJECT COSTS AND BENEFITS, BY YEAR TO 2035-36 ($M, 2016/17 DOLLARS)



SOURCE: ACIL ALLEN CONSULTING

Details of the assumptions and attributions used to arrive at these figures are included in the full case study in Appendix F.

The benefits described are those arising from just three of the 243 projects conducted on the synchrotron as a result of the SIEF funding. While the other research projects have not been investigated in sufficient detail to judge the extent to which they might also deliver benefits, it is highly unlikely that would fail to do so. Given this, the benefits described above are highly likely to be an underestimate of the total benefits which will flow from the synchrotron research.

The other benefits from the synchrotron SRP activity could reasonably be assumed to over time potentially add an estimated $700 million to the overall benefits of the synchrotron activity.

4.2 The benefits of SIEF's support for other Special Research Program activities

The Australian Square Kilometre Array Pathfinder (ASKAP) is CSIRO's innovative radio telescope located at the Murchison Radio-astronomy Observatory (MRO) in Western Australia, about 350 km northeast of the coastal town of Geraldton and about 750 km northeast of Perth.

ASKAP will be the world's largest, most sensitive survey radio telescope.

When fully commissioned, ASKAP will be the world's largest, most sensitive survey radio telescope. It is made up of thirty-six steerable 12-metre antennas, working together as single instrument, spread out in a configuration to maximise science capability. Each antenna will be fitted with one of CSIRO's award winning Phased Array Feed (PAF) receivers.

PAFs are multi-pixel imaging devices that work like a digital camera, only in radio waves. PAFs allow huge areas of the sky (30 square degrees) to be covered at once – many times more area than is possible with traditional receivers. The antennas are connected via fibre optic cables to a control building where the data are digitised and filtered. Each antenna generates 30 beams (or views on the sky) which are analysed on site before being sent 800 km over fibre to the supercomputer at the Pawsey Centre in Perth for processing.

As the number of PAFs installed on ASKAP antennas increases, the scientific capability of the telescope is boosted substantially. With additional funding from SIEF (matched by CSIRO), the project is enhancing and extending the ASKAP through the addition of PAFs and their associated digital systems, thus helping to ensure delivery of this revolutionary telescope at close to the scientific capability required to ensure optimum scientific impact and lasting benefit to Australia.

As well as being a world-leading telescope in its own right, ASKAP is also a precursor to the international Square Kilometre Array (SKA) radio telescope to be hosted in Australia and southern Africa. As part of SKA Phase One (SKA1), the 36 existing ASKAP antennas will be expanded out to 96 dishes, forming SKA1-Survey. Equipped with PAF technology, this element of the SKA will be able to survey large areas of the sky in great detail.

Over the life of the SIEF SRP activity, the broader ASKAP Program has come a long way, with the success of ASKAP's original test array of six antennas fitted with first generation (Mk I) PAFs being a major outcome. To date, nine papers have been published and more are in the pipeline as observational data, available on the web, is proving to be a rich source of novel findings for astronomers.

The prototype Mk II PAF was installed on an ASKAP antenna in September 2014. It operated reliably through the heat of summer and heavy rain and, more importantly, demonstrated the expected significant improvement over the Mk I PAFs.

The first 'production' Mk II PAFs were installed in June 2015 and the first image was made just three months later. By May 2016, 12 SIEF-funded Mk II PAFs were installed; and in October 2016 ASKAP Early Science had commenced with these 12 PAFs. At the time of writing, 24 Mk II PAFs have been installed, with the aim being to have all 30 installed by the end of 2016.

CSIRO has now sourced sufficient funds to upgrade ASKAP and fit all 36 antennas with Mk II PAFs, allowing ASKAP to reach its full potential. ASKAP will be the world's pre-eminent survey instrument for at least the next decade; and will complement the planned telescopes of the international SKA project.

Over the life of the SIEF SRP activity, the rate of PAF production improved as a result of streamlining production processes and cross-skilling the workforce. CSIRO was also able to slot into its production line the manufacture of a PAF for Germany's Max Planck Institute for Radio Astronomy. It has also secured a contract to make another PAF for Jodrell Bank Observatory in the UK.

Industry participation in ASKAP has created strong collaborations with a variety of organisations, including niche R&D companies; and has resulted in commercial contracts with high-volume manufacturers, technology systems vendors, site services and installations firms, and energy and data transmission specialists. Engagement occurs with larger technology and civil engineering firms, and also with smaller local suppliers. Benefits that arise from such collaboration include:

— technology transfer between astronomy and industry
— access to new technology and/or larger markets
— collaborative R&D between global firms and Australian producers, leading to up-skilling and enhanced capability.[14]

For example, high-end electronics assembly supplier, Puzzle Precision, has expanded into premises ten times the size of its old factory and has increased its workforce by a similar factor. The company reports a sustained increase in business; and now boasts a suite of clients from Australia and around the world.

Solutions developed by industry for ASKAP, include power distribution, remote access, operations, and high-tech infrastructure.

Solutions developed by industry for the non-astronomy challenges facing ASKAP, including power, remote access and operations, and high-tech infrastructure, will also have applications elsewhere in Australia and around the world.

While the benefits of the ASKAP SRP activity have not been examined in detail, it is clear that it has already delivered a number of benefits in terms of growth of employment and exports. However, no value has been assigned to the ASKAP SRP activity for the purposes of this review of SIEF.

14 *ASKAP Industry Engagement Case Study: Manufacturing*, nd, CSIRO and http://www.ska.gov.au/Industry/Pages/IndustryInvolvement.aspx

5 BENEFITS OF THE PROMOTION OF SCIENCE PROGRAM

5.1 The elements of the Promotion of Science program

Australia needs a secure pipeline of STEM researchers flowing into its innovation ecosystem. This will ensure the continuity of Australian research and the economic benefits it generates. Developing a STEM workforce is a long term process, and requires strong collaboration between industry, PFRAs, universities, and researchers. This support is especially critical for Early Career Researchers (ECRs) who are either completing Honours degrees, PhDs or post-doctoral studies, or who are looking for short-to-medium-term contracts as researchers in a very competitive environment.

SIEF's Promotion of Science program supports the creation of a nationally significant STEM workforce.

The objective of SIEF's Promotion of Science (PoS) program is to support the creation of a nationally significant STEM workforce in Australia by supporting researchers to develop their research career and the skills and experience that will enhance their career mobility. To date, SIEF has invested $19.4 million in PoS activities. This includes supporting research undertaken by ECRs, appointing scientists to university positions, and – most importantly – providing scholarships and fellowships.

The scholarships and fellowships component of the PoS program consists of three separate elements:

— Fellowships and Scholarships

— The SIEF-Australian Academy of Science Fellowships to the Lindau Nobel Laureate Meetings.

— The STEM+ Business Fellowships.

At the time of this review, around 103 individual grants of financial assistance had been provided under these three elements.

5.1.1 Fellowships and Scholarships

The SIEF fellowships and scholarships element of the PoS program has five components:

— *John Stocker Postdoctoral Fellowships*. These Fellowships provide support for collaborative projects between PFRA's and universities with a strong preference for end-user/industry engagement in the project.

— *John Stocker Postgraduate Scholarships*. This funding provides scholarships over a three year period with preference for research in the priority research areas of information and communication technology (ICT), mathematics, and engineering.

— *John O'Sullivan Postgraduate Scholarship*. This Scholarship is awarded to a student conducting research in the area of the utilisation of scarce radio spectra.

- *The Undergraduate Degree Scholarships program*. This program offers scholarships to Science/ICT or Engineering undergraduates from Indigenous or rural, and of low socio-economic, backgrounds.
- *Honours and Vacation Scholarships program.* This program offers scholarships in areas with a mathematics/numeracy component.

5.1.2 Lindau Fellowships

The SIEF-Australian Academy of Science Fellowships to the Lindau Nobel Laureate Meetings provide a unique opportunity for young Australian researchers. The Lindau Nobel Laureate Meetings are held annually at Lake Constance, Germany. The Fellowships provide a platform to facilitate encounters between Nobel Laureates and the world's best young scientists of tomorrow. They also provide the opportunity for young researchers to network with elite scientists from around the world. SIEF provides support for up to 15 ECRs to attend the Lindau meeting each year.

5.1.3 SIEF STEM+ Business Fellowships

The STEM+ Business Fellowship Program provides a mechanism for ECRs to build new skills and relationships with industry. Under the program, ECRs, research organisations, and small and medium sized enterprises (SMEs) work together to develop innovative commercial solutions that enhance Australia's national competitiveness.

5.2 The benefits of the Promotion of Science program

5.2.1 Alignment with Australia's innovation priorities

Most research undertaken by SIEF-supported researchers addresses the Government's National Science and Research Priorities.

The SIEF PoS Program supports outstanding candidates at the early stages of their careers. It provides them with financial support to undertake research across a broad spectrum of topics and helps them reach their potential. A key selection criterion for the PoS Programs is that the research being undertaken by the ECRs should address one of the National Science and Research Priorities set by the Australian government. Of the $19.4 million SIEF has invested in the PoS program, 87% is aligned to these priorities. This demonstrates that SIEF is playing a key role in ensuring that the National Innovation System has access to a talent pool of researchers who are trained in the areas of National Science and Research Priorities.

5.2.2 Supporting ECRs career progression

A 2012 survey of Australian researchers (n = 1,203) commissioned by the Department of Industry, Innovation, Science, Research, and Tertiary Education (DIISRTE) identified job security, uncertainty of funding, and workload as key concerns for Australian researchers.[15] The survey also suggested a number of measures to help researchers to develop their careers. These included providing support for:

- advice and mentoring for researchers
- collaborations, mobility, and industry linkages
- clearer career pathways for researchers
- training programs
- tenure, permanency, and long-term contracts.

To evaluate the impact of SIEF's PoS program and the benefits it delivers to ECRs, an evaluation framework was created based on these elements. The evaluation team conducted an online survey and interviews with SIEF ECRs. The aim was to assess if working on SIEF projects had given the ECRs access to the above elements, thereby assisting them to address the hurdles faced in establishing a stable career in their chosen field of research. In total, 115 ECRs

15 *Career support for researchers*, 2012 available from http://www.acola.org.au/index.php/projects/rws

participated in the survey, including 40 ECRs associated with PoS activities.[16] The ECR survey questions are provided in Appendix G.

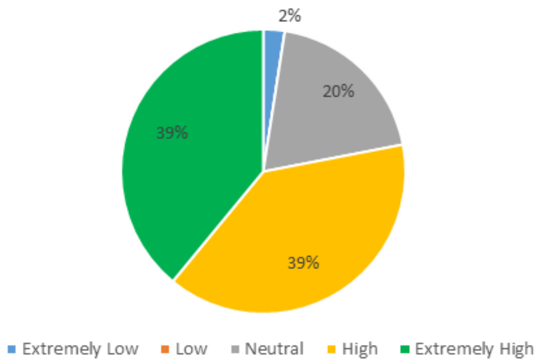
Advice and mentoring for researchers

In the 2012 DIISRTE-supported study, respondents expressed the need for guidance, mentoring, and advice to help develop their careers. They described the career path of an academic as "mysterious"; and, consequently, that guidance and advice was required to cope with life as a researcher.

SIEF-supported Early Career Researchers appreciated the assistance they received in developing collaborations and mobility..

In the SIEF survey, 39% of the ECRs rated the quality of the advice received from other researchers while working on PoS project as *extremely high*, while another 39% rated the quality as *high* (see **Figure 5.1**).

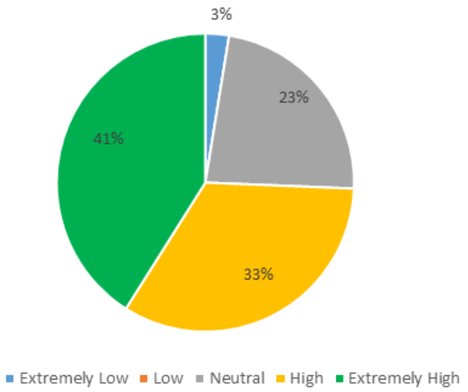
FIGURE 5.1 RATING OF ADVICE RECEIVED FROM OTHER RESEARCHERS



SOURCE: SEIF SURVEY OF ECRS

Just over 40% of the ECRs also rated the quality of mentoring received from other researchers as *extremely high,* and 33% rated the mentoring quality as *high* (see **Figure 5.2**). Only 3% rated the quality of the mentoring received from the other researchers as *extremely low*.

FIGURE 5.2 RATING OF MENTORING RECEIVED FROM OTHER RESEARCHERS



SOURCE: SEIF SURVEY OF ECRS

This indicates that ECRs value the mentoring and advice provided formally or informally by their supervisors or colleagues while working on the SIEF-funded PoS activities.

Collaborations, mobility and industry linkages

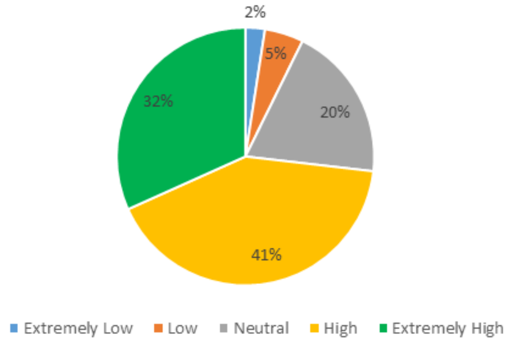
In the DIISRTE-supported study, the researchers highlighted the benefits of closer collaborations with industry and government. They noted that mobility offers the potential of joint work, new

16 ECRs are also supported by the RP. However, the results discussed in this section relate only to the views of the ECRs supported through the PoS.

sources of employment, and funding. They also noted that, in general, mobility between the different sectors in the Australian innovation system is challenging.

In the SIEF survey, 74% of ECRs rated SIEF's support for developing collaborations as either *extremely high* or *high* (see **Figure 5.3**).

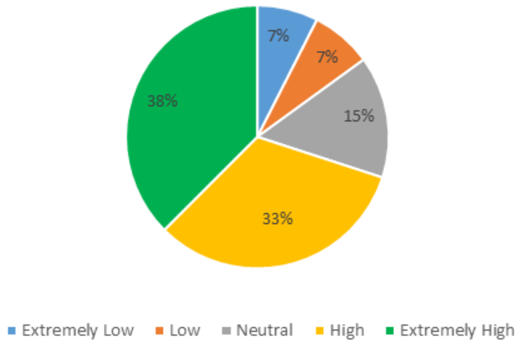
FIGURE 5.3 RATING OF SIEF'S SUPPORT FOR DEVELOPING COLLABORATIONS



SOURCE: SIEF SURVEY OF ECRS

Over 70% of respondents rated SIEF's support for developing their mobility either as *extremely high* or *high* (see **Figure 5.4**). Only 14% of the respondents rated SIEF's assistance in this area as *low* or *extremely low*.

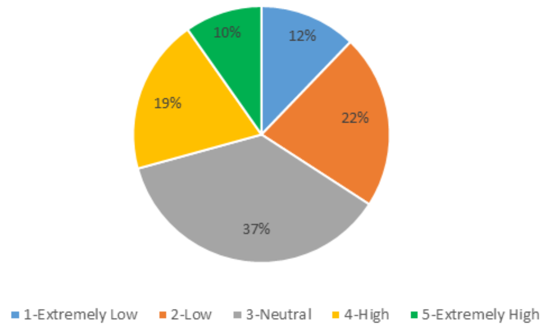
FIGURE 5.4 RATING OF SIEF'S SUPPORT FOR DEVELOPING ECR MOBILITY



SOURCE: SIEF SURVEY OF ECRS

In relation to helping them to develop industry linkages, 29% of the ECRs rated SIEF's assistance as *extremely high* or *high,* while 34 % of ECRs rated the assistance as *low* or *extremely low* (See **Figure 5.5**).

FIGURE 5.5 RATING OF SIEF'S SUPPORT FOR DEVELOPING INDUSTRY LINKAGES



SOURCE: SIEF SURVEY OF ECRS

These results suggest that ECRs rate the assistance they received from SIEF in developing collaborations and mobility very highly. However, it seems that there is scope for improvement in how SIEF assists ECRs to develop industry linkages. Doing so may be a challenge as many PoS activities are providing support to ECRs working in emerging areas of science with little or no connection to, or need for collaboration with, industry partners at this early stage.

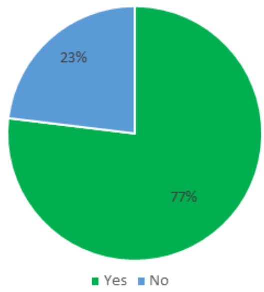
Clearer career pathways for researchers

SIEF-supported Early Career Researchers rated the quality of career path advice highly.

The researchers who participated in the DIISRTE-supported survey stressed the need for a clearer articulation of the career pathways for researchers. They noted the difficulties in assessing career pathways and opportunities; and that authoritative information and advice on these areas was essential for their career progression. This seems to be especially important for researchers in the early stages of their career.

Over three quarters of the ECRs who participated in the SIEF survey reported that SIEF's support had helped them identify career pathways in research and other areas (see **Figure 5.6**). This suggests that SIEF's support has helped most ECRs to better identify career options in research and other areas.

FIGURE 5.6 DID SIEF HELP YOU IDENTIFY A CAREER PATHWAY?

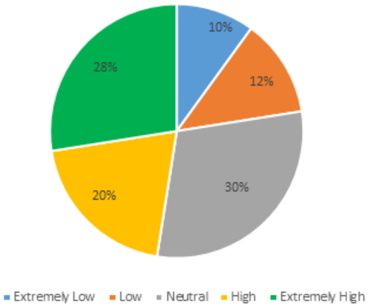


SOURCE: SIEF SURVEY OF ECRS

Training for ECRs

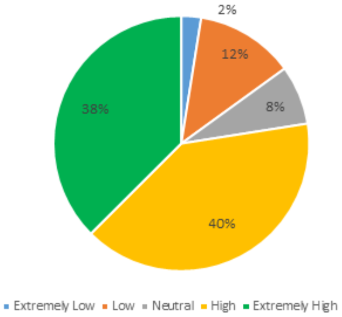
The DIISRTE-supported study found that training in generic research and non-research skills makes ECRs more employable. In their responses to the SIEF survey, almost half of the ECRs rated the quality of the technical training they had received as a result of the SIEF support as *extremely high* or *high* (see **Figure 5.7**). Similarly, 78% of respondents rated SIEF's support for non-technical training as either *extremely high* or *high* (See **Figure 5.8**).

FIGURE 5.7 RATING OF SIEF SUPPORT FOR TECHNICAL TRAINING



SOURCE: SIEF SURVEY FOR ECRS

FIGURE 5.8 RATING OF SIEF SUPPORT FOR NON-TECHNICAL TRAINING



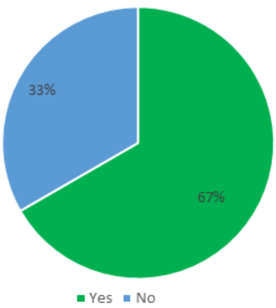
SOURCE: SIEF SURVEY OF ECRS

Tenure, permanency, and long-term contracts

Over two thirds of SIEF-supported Early Career Researchers reported that their SIEF work experience led to further employment.

In the DIISTRE-supported survey, job instability and lack of security were nominated by the researchers as two of the stressful and challenging aspects of the Australian system. In the 2016 SIEF survey, over two thirds of the respondents reported getting further employment owing to their SIEF work experience (See **Figure 5.9**).

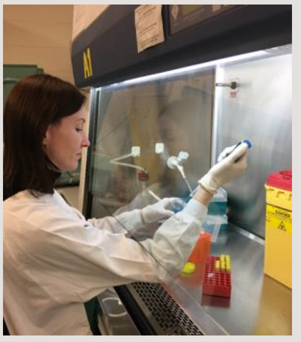
FIGURE 5.9 DID SIEF SUPPORT ASSIST YOU TO GAIN FURTHER EMPLOYMENT?



SOURCE: SIEF SURVEY OF ECRS

To obtain more insights in this area, the evaluation team interviewed two of the SIEF ECRs to understand their overall career progression and SIEF's contribution to it. The insights gained from these interviews can be found in **Box 5.1** and **Box 5.2**.

BOX 5.1 DR CAROLINE BULL'S EXPERIENCE WITH SIEF



Dr Caroline Bull has an Honours degree in Science majoring in biochemistry and immunology from the University of Adelaide. Her PhD in immunology was also awarded from the University of Adelaide; and was completed with the assistance of CSIRO. After completing her PhD she took up a SIEF-funded postdoctoral fellowship.

Working in collaboration with her supervisors, Professors Michael Fenech (CSIRO) and Helen Christensen (Black Dog Institute), and other researchers, Caroline's research explored how telomeres (the caps at the end of each strand of DNA that protect our chromosomes) are damaged by psychological stress. The study also included an examination of the interactive effect between malnutrition and psychological stress on telomere damage. Caroline believes that the link between psychological stress and physiological damage is the "*holy grail of this particular area of research*".

Caroline found her SIEF postdoctoral position highly beneficial compared with other postdoctoral opportunities. She noted that:

> *The SIEF project has an incredibly clear structure to it; and because of the application process, there was a very clear project focus and plan. One of the key differences was the budget and the operating funds available, and the requirement for travel, which was a lot more generous than other fellowships.*

The SIEF project enabled her to conduct and manage a full clinical trial process from start to finish with "*real human subjects*" which she describes as the "*highlight of my scientific career*". It also provided her with the opportunity to present her research at numerous significant international conferences.

As well as enabling her to implement the skills gained through her PhD studies, the SIEF fellowship provided Caroline with the opportunity to extend these skills and establish herself as a more 'saleable' independent researcher. Importantly, her collaboration with senior researchers in the SIEF project provided Caroline with the opportunity to develop important additional skills in grant and proposal writing, communication, and project and budget management.

Without the SIEF funded project, it is highly probably that Caroline would have looked for research opportunities overseas as her only other Australian-based opportunity at the time was an unfunded postdoc position which she suggests was "likely to fall over".

Caroline credits her SIEF experience with assisting her to secure her current permanent position with CSIRO as it allowed her to demonstrate clearly her ability to function as an independent researcher. She is currently working on several important commercially-focused projects driven by her passion to enable people to live longer and healthier lives through preventative health measures.

SOURCE: CSIRO ECRS SURVEY

BOX 5.2 DR ANAIS PAGES' EXPERIENCE WITH SIEF

Dr Anais Pages studied for her PhD in geochemistry at Curtain University after completing her Bachelor and Master's degrees in earth and marine sciences at the University of Bordeaux. She commenced her SIEF-funded project on the completion of her PhD studies.

Anais' SIEF project involved exploring sediment-hosted metal deposits and the function of organic matter in trapping metals, as well as examining the evolution of life following the Cambrian explosion (c. 540 million years ago) and the role of metals in the enzymatic function of the animal life which emerged at this time. This cutting-edge project, combining organic and inorganic geochemistry, was led by Anais – a significant achievement for an early career researcher. While she had a supervisor, she was allowed the freedom to "*do the research the way [she] wanted to*", including driving the collection and analysis of data from Cambrian period deposits in South China and Australia.

One of the key benefits of the SIEF project identified by Anais over other forms of postdocs was the capacity it provided through its funding and management structures for her to engage in collaborative activities with significant international research-focused organisations such as NASA, the US Geological Survey, the Chinese Academy of Science, Kiel University, and Yale University. In addition, the SIEF project provided Anais with further technical and professional training, significant personal networking and collaborative opportunities, and the chance to develop additional skills in project management, negotiation, and leadership.

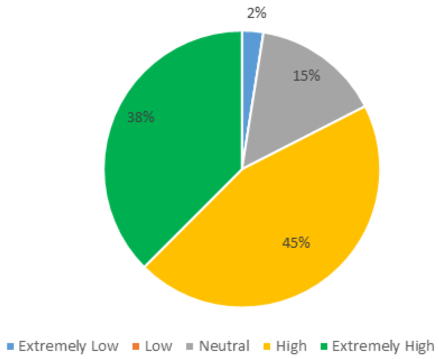
While Anais had other postdoc opportunities available to her after completion of her PhD, she acknowledges that the SIEF project was the only one which enabled her to continue to work specifically her within her chosen field of research. It also offered her a 3-year fellowship instead of 2 years, which gave her more time "to develop a project, build something, and get something from it".

As a result of her outstanding research efforts on the SIEF project, and the broader benefits of her research (particularly for mineral exploration), Anais has been presented with two significant CSIRO awards – the 'CSIRO Mineral Resources award for Science Achievement – Early Career Researcher', and the 'CSIRO John Philip Award for Promotion of Excellence in Young Scientists'. Anais now has a permanent position within CSIRO; and is working on further economically and environmentally beneficial solutions for mineral exploration and extraction challenges involving the use of organic material.

SOURCE: CSIRO ECRS SURVEY

As can be seen from **Figure 5.10**, a clear majority of ECRs rated SIEF's support in progressing their careers either *extremely high* or *high*.

FIGURE 5.10 RATING OF SIEF'S SUPPORT IN PROGRESSING CAREERS



SOURCE: SURVEY OF SIEF ECRS

Overall, the SIEF PoS program has been successful in helping Early Career Researchers advance their careers.

The above discussion indicates that the PoS program has been successful in providing mentoring and advice to ECRs, helping them to develop collaborative relationships, improving their career mobility, and enhancing both their research and non-research skills. The SIEF support received has also assisted the majority of the ECRs to obtain further employment. Overall, SIEF's PoS program has clearly enabled most of the participating ECRs to develop their research track record and establish their research careers.

6 HAS SIEF DELIVERED VALUE?

6.1 The estimated financial value delivered by SIEF

ACIL Allen has considered the potential benefits associated with eight activities selected as case studies for this review, including the results of the eReefs project which was examined by ACIL Allen in early 2016. For one of these activities, namely the ARCF, it was clear that it was still too early to be able to confidently quantify what the potential benefits might be. However, **Table 6.1** summarises the results of the benefit cost analyses conducted for the other case studies.

The conservatively estimated net present value of the case studies in this report exceeds $4 billion over the next 20 years.

Each of the case studies is estimated to have a benefit cost ratio that is greater than one. In other words, the potential benefits of the activity outweigh its costs. In the case of three of the case studies, the estimated benefits from any one of them on its own easily exceed the total cost of the SIEF Portfolio.

TABLE 6.1 SUMMARY OF COST-BENEFIT ANALYSIS RESULTS

Case study	PV of SIEF funding	PV of benefits	NPV	BCR
	($m)	($m)	($m)	
Energy waste	$7.3	$151.6	$144.3	20.8
Early nutrition	$6.2	$428.2	$422	69.1
Plant breeding	$6.2	$2,825.3	$2,819.1	459.5
RAFT for medical applications	$4.8	$53.2	$48.4	11.1
Distal footprints	$4.3	$23.4	$19.2	5.4
eReefs[a]	$4.3	$11.9	$7.6	2.8
Synchrotron	$11.9	$811.2	$799.3	68.2
Seven case studies	**$44.9**	**$4,304.9**	**$4,259.9**	**95.9**

[a] The data for the eReefs case study is based on the results of earlier work by ACIL Allen that examined the impact and value of CSIRO research. The eReefs project was funded in part by SIEF and to arrive at the figures above, 10% of the estimated benefits of eReefs has been allocated to SIEF.

SOURCE: ACIL ALLEN CONSULTING

Despite the conservative estimates of the potential benefits that might be delivered by the case studies, the total estimated benefits comfortably exceed the costs of the SIEF Portfolio by more than two orders of magnitude.

As with any estimate of a potential future benefit from a research activity, there is a non-zero chance that the anticipated benefit will ultimately prove to be unrealisable. However, ACIL Allen judges that the probability that none of the many identified potential benefits from the case studies will be realised as being near zero. Furthermore, for most of the case studies multiple pathways have been identified through which benefits could be delivered. A number of these paths could on their own deliver benefits that exceed the total cost of the SIEF Portfolio.

In addition, ACIL Allen has intentionally sought to use extremely conservative assumptions to arrive at the figures provided in **Table 6.1**. A conscious decision not to value a number of additional potential benefits associated with the case studies has also been made. These additional benefits could deliver significant additional value. Consequently, ACIL Allen regard the estimates of benefits as a relatively conservative lower bound on the potential value that SIEF may deliver.

This view is further supported by the fact that less than half the Research Projects supported by SIEF have been examined in detail for this report. It would be unusual if some proportion of the projects that were not examined did not also deliver benefits in the medium to long term.

The case studies described in this report are likely to be representative of the full SIEF Portfolio.

The information in **Table 6.1** suggests that the SIEF Research Projects selected as case studies are broadly similar in nature to the 'other Research Projects' in terms of their performance against the indicators listed in **Table 2.1**. While this clearly provides no guarantees that the 'other Research Projects' will deliver benefits similar to those of the case studies, it does provide some degree of confidence that they might do so. The number of patents generated by the 'other Research Projects' particularly supports this view.

Given the uncertainty around the eventual outputs of the 'other Research Projects', the value that they might deliver has not been quantified. It is sufficient to note that the fact that they are highly likely to provide some (unspecified) level of benefit provides greater confidence that the value delivered by SIEF is likely to outweigh the program's costs.

6.1.1 What is a 'norm' for benefit cost ratio for R&D?

SIEF benefit cost ratios are broadly comparable to those reported in other studies.

Some might argue that the estimated benefit cost ratio of just under 95 for all the case studies listed in **Table 6.1** is high. **Box 6.1** provides some examples of benefit cost ratios for various investments in R&D. From the examples listed we see benefit cost ratios that range from 9 to 85. The range of benefit cost ratios are broadly comparable to those which have been estimated for the majority of SIEF case studies.

There is of course an outlier among the SIEF case studies, namely the Plant Breeding project. The benefit cost ratio for this project is just under 460; and this is certainly a very large ratio by most standards. As with all the other case studies, conservative assumptions have been made regarding the potential impact of this project. However, the scale of the market is such that even a very small impact can produce very significant benefits.

If the Plant Breeding project is excluded from the calculations, then the estimated benefit cost ratio falls to just over 37. This lies in the mid-range of the ratios listed in **Box 6.1**. ACIL Allen believes that there are a number of reasons why research supported by a fund such as SIEF might have an estimated benefit cost ratio of this magnitude. This is discussed further in **Section 6.2**.

BOX 6.1 EXAMPLES OF BENEFIT COST RATIOS FOR R&D INVESTMENTS

It is instructive to compare the estimated benefit cost ratio that flows from the analysis of SIEF-supported research to that achieved by other research projects funded by other research organisations. A review of past benefit cost analyses of various research projects identified a range of different benefit cost ratios. For example:

— Grape and Wine Research and Development Corporation (2001) (estimated a BCR of 9)
— Productivity Commission Inquiry Report (2007) (estimated a BCR of 40)
— The Australian Centre for International Agricultural Research (ACIAR) (2011) (estimated a BCR of 85)
— CSIRO Salmon Breeding Case Study (2015) (estimated a BCR of 27)

SOURCE: CSIRO

6.2 Other value delivered by SIEF

SIEF has also delivered additional non-quantifiable benefits.

SIEF has also delivered benefits that are not easily quantified, but which nonetheless appear likely to provide substantial long term value. These additional (non-quantified) elements of value include:

— The benefits that flow from SIEF's investment in three Research Infrastructure activities. This investment has:
  – mobilised more than four and a half times SIEF's investment from other organisations
  – delivered significant and valuable research capability to existing National Sciences Precincts in Perth, Clayton, and Canberra
  – supported the creation of common access arrangements that will help to ensure that the infrastructure is effectively managed and utilised by researchers
  – already attracted the attention of researchers and businesses both in Australia and overseas.

— The benefits that the Promotion of Science program has delivered, including:
  – fostering the skilled, experienced, and highly motivated early-career researchers who will become the research and innovation leaders of tomorrow
  – encouraging the creation of linkages and collaborations, both among researchers and among researchers and businesses
  – helping to provide a career structure for early career researchers that encourages them to develop and grow as members of the research community.

CASE STUDY: PLANT BREEDING

A

BOX A.1 PLANT BREEDING - EXECUTIVE SUMMARY

Key findings

The Plant Breeding Research Project has produced two potentially important outputs, namely:

- Finding an explanation for why second and subsequent generations of hybrids have progressively less vigour than their preceding generations.
- Identifying how to make plants become apomictic. If this can be achieved, hybrid vigour can be captured and higher yields maintained.

Innovation impact

The collaboration with Nuseed and the support provided by the Gates Foundation both highlight the potential for the results of this project to have a significant impact on local and global food security and sustainability.

This case study uses the evaluation framework outlined in the CSIRO Impact Evaluation Guide. The results of applying that framework to the Plant Breeding case study are summarised in Figure 1.

A.1 Purpose and audience for case study

This case study describes the economic, environmental and social benefits arising from SIEF's funding for the Plant Breeding project (RP01-006).

This evaluation is being undertaken to assess (to a range of stakeholders) the positive impacts arising from the Plant Breeding project undertaken by CSIRO. This case study can be read as a standalone report or aggregated with other case studies to substantiate the impact and value of SIEF's activities as a whole relative to the funds invested in these activities.

This information in this case study is provided for accountability, communication and continual improvement purposes. Audiences for this report may include Members of Parliament, Government Departments, SIEF, CSIRO, other researchers and the general public.

FIGURE A.1 PLANT BREEDING CASE STUDY – IMPACT FRAMEWORK DIAGRAM

INPUTS	ACTIVITIES	OUTPUTS	OUTCOMES	IMPACTS
– SIEF investment – In kind support from CSIRO	– Research	– Sustainable increased yields in hybrid plants – A pathway to getting plants to become apomictic – Publications – Farrer Memorial Medal 2014 to Liz Dennis	– Gates Foundation funding for a CSIRO-led consortium – New collaborative project with Nuseed and the University of Technology Sydney – New contract from GIFS Canada (University of Saskatchewan) for work on lentils – Collaboration and in-kind support from Prof Wu of University of Sichuan China for rice – Possible future revenues for CSIRO	– Economic benefits for growers – A World better able to feed its population – Employment growth – Contribution to GDP – Better environmental or social outcomes

SOURCE: ACIL ALLEN

A.2 Background

Food security is one of the greatest challenges facing the future of our planet. The World's population is expected to reach 9 billion by 2050. This means that in the next four decades, the present level of food production must be significantly increased. Societal expectations of modern agribusiness demand decreased dependence on agrichemicals and increased stewardship of land and water resources, conserving them for future generations. Increased food production will need to be achieved on existing arable land.

Plant breeding programs together with improved management regimes have led to steady increases in crop yields over the past five decades. However the rate of improvement in yields has plateaued and the relatively small annual incremental improvements in yield (around 0.5-1.5% a year) will not achieve the necessary 'step change' required to have any chance of achieving the necessary doubling of yields. While our capacity to identify desired traits in crops has improved, the capability to significantly increase yield and bring together traits required has not. Better, high yielding crops are urgently needed.

For many crops, plant breeders have developed hybrid seed systems with increased yields over and above either of the parents (often referred to as hybrid vigour). Hybrid crops form the basis of world production crops such as corn, canola, sun flowers, sorghum and rice. However the underlying molecular and cellular basis of hybrid vigour remains poorly understood. Breeders select the parents which give high yielding progeny, and cross breeding is labour intensive and poses technical challenges.

The ability to breed hybrid plants with improved yield (heterosis) without having to go through multiple breeding cycles would be a major advantage. Locking in the gains from hybrid vigour is also an issue, because the benefits of heterosis are gradually lost as the higher yields are inefficiently transmitted from one generation to the next. Thus seeds from high yielding hybrids cannot simply be re-sown.

The Plant Breeding project started in 2010, building on existing strengths of CSIRO. The project has two related components, which aim to provide new approaches to plant breeding that have the potential to create and perpetuate major yield increases. The first component is seeking to understand why first generation hybrids have higher yields (heterosis) than their parents, and how these yields can be maintained in subsequent generations.

The second part of the project has sought to induce and control the expression of asexual seed formation (apomixis). Progeny of apomictic plants are clones of the mother plant. This occurs naturally in some plants including species such as dandelions, but not in most of the world's major food, feed, and fibre crops. CSIRO has led the identification of apomixis genes in *Hieracium*.[17] The two genomic regions responsible for apomixis and seed formation have been identified in previous work undertaken in collaboration with the New Zealand Institute for Plant and Food Research Ltd. The second part of this SIEF project sought to build on this previous work and to identify the causal sequences involved. This could lead to mimicking apomixis behaviour in plants that are not naturally apomictic.

While each of this project’s components are valuable in their own right, they are related. If heterosis can produce new higher yield varieties of crops, then apomixis can be used to lock in these benefits.

A.3 Impact Pathway

A.3.1 Project Inputs

The total cost for the Plant Breeding project was about $7.7 million in cash and in-kind contributions. The SIEF contributed $4.5 million in cash (around 58% of the total cost), CSIRO contributed the rest as in-kind support (see **Table A.1**).

TABLE A.1 SUPPORT FOR THE SIEF PLANT YIELD PROJECT

Contributor / type of support	2010-11	2011-12	2012-13	2013-14	Total
Cash					
SIEF	$900,000	$1,439,461	1,542,650	$617,889	$4,500,000
In-kind					
CSIRO	$431,135.00	$1,037,705	$912,416	$811,485	$3,192,741
Total	**$6,406,304**				

A.3.2 Project activities

Heterosis

The first element of this project has developed an understanding of the molecular and cellular basis of heterosis. The research has found that changes in organisms caused by modification of gene expression (epigenetic controls) are of central importance to increased yields in first

[17] A daisy-like plant.

generation hybrids. Two epigenetic systems are involved in the production of small RNA molecules. These influence DNA methylation patterns. The project has identified a novel mechanism of alteration of the methylation of the hybrid genome which underlies changes in gene activity levels. This has led to an explanation for why second generation and subsequent generations of hybrids have progressively less vigour than their preceding generations.

With this knowledge, the SIEF project team has developed genetic processes to make pure breeding lines. Using *Arabidopsis*,[18] they took the best first generation hybrids and used them to create a second generation. This process was repeated through to the sixth generation. At fifth generation, and subsequently, vigour was being consistently maintained. Subsequent work has sought to understand how this stability is being maintained.

This work is now being extended to other plant species. Canola is of particular relevance because variable weather conditions in Western Australia make farmers reluctant to invest in hybrid seed. However disease resistance is a major issue in canola and new hybrids are needed every 2-3 years. The application of this SIEF project outcomes to canola would be very beneficial.

Other plants that can potentially benefit from this work include lentils, rice, field peas, sorghum, tomatoes and chick peas.

Apomixis

The SIEF project team has studied the molecular and cellular basis of apomixis in *Hieracium*. The team has found that the genetic locus essential for forming the endosperm[19] is dominant, and different and independent from two other previously known genetic loci that control apomixis. The work has examined how to get plants to become apomictic. If this can be achieved, hybrid vigour can be captured and higher yields maintained.

Apomixis is considered to be possibly the most important trait agricultural biotechnology could confer to crops in the foreseeable future. For example, with apomixis, wheat yields could increase by 15% and in the case of rice, the increase in yield could be as much as 30%.

A.3.3 Project outputs

The major outputs from this project have been new knowledge of two important issues in increasing plant yields. The heterosis element of the project has provided the first understanding of the mechanisms of heterosis. This work has generated knowledge of the underlying molecular and cellular mechanisms operating in first generation hybrids which should provide increased possibilities to use hybrid vigour to enhance production levels in many crops.

The apomixis element of the project has identified two groups of genes that are likely to control apomixis. A particularly significant outcome of this project has been the genetic uncoupling of autonomous endosperm formation from parthenogenesis in *Hieracium*. It now looks possible to attempt to change the sexual reproduction in a hybrid to mimic apomixis.

Publications

The heterosis work has resulted in 11 publications, including 4 in the high impact factor journal *Proceedings of the National Academy of Science USA.* The apomixis work has resulted in 16 publications including in journals with high impact factors. In one journal, the paper was the featured article, and in this and another example the work features on the journal's cover page.

Further publications are in preparation.

Awards

Liz Dennis received the Farrer Memorial Medal in 2014.

Innovation / commercialisation

CSIRO collaboration with Nuseed is resulting in innovation and expected commercialisation.

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[18] A small flowering plant related to cabbage and mustard.
[19] Plant tissue produced inside the seeds of most flowering plants around the time of fertilisation.

A.3.4 Project Outcomes

Heterosis

The outcomes of the Plant Breeding project's research on heterosis have generated a significant number of additional collaborations, namely:

— A new line of research has commenced through a collaborative project with Nuseed, an Australian company. Nuseed has provided Canola genetic material for use in the research. This work could result in end-point royalties (a levy on the harvest).

— Another agreement with Nuseed involved in the application of the heterosis work in lentils. If the results of this collaborative research is successful then any end-point royalties would be shared 50% Nuseed, 25% to the University of Technology Sydney and 25% to CSIRO.

— CSIRO has also partnered with the Saskatchewan-based Global Institute for Food Security to work on grain legumes (which pollinate the closed flower, preventing the formation of hybrids). The Institute is supported by Pulse Canada, the national industry association that represents growers, processors and traders of pulse crops in Canada. Canada is the world's second largest grower of lentils (after India).

— CSIRO is also working with the Rice Research Institute, Sichuan Agricultural University in China to see whether the heterosis results can be applied in rice. If successful, the SIEF-funded work would completely transform the hybrid rice industry.

In addition, valuable training in molecular biology, genomic and epigenomic technologies has been provided for five Postdoctoral Fellows for the Heterosis project.

Apomixis

The significant level of achievement obtained in the apomixis research project is evidenced by the support from the Bill and Melinda Gates Foundation for a five-year $US 22 million CSIRO-led project involving a total of seven international institutions including Pioneer DuPont.[20] Each of the partners is contributing their particular expertise. In addition the apomixis project team has developed bioinformatics tools to visualise genes in *Hieracium*.

There have also been 16 research papers published as a result of this project. CSIRO has also formed a partnership with the Adelaide based ARC Centre of Excellence in Plant Cell Walls to continue aspects of the *Hieracium* work.There are very large potential benefits from this research in relation to food and fibre production from plants. Increases in plant yields of 15-30% are possible (for canola, around 20%).

As can be seen above, the outcomes of the Plant Breeding research are of interest to seed companies.

Table A.2 sets out current Australian and global production figures for selected major crops. Note that world production and prices can vary significantly from year to year. The estimated total value of current Australian production for the crops listed is approximately $13.6 billion.

Based on the prices and Australian production volumes listed in the table, a 20% increase in Australian production would be worth $2.7 billion per annum.[21]

TABLE A.2 PRODUCTION AND VALUE OF SELECTED CROPS

	Australian production (million tonnes)	Value ($million)	World production (million tonnes)	Price per tonne ($)
Rice	1	530	738	530
Canola	4	2,240	69	560
Sorghum	1.4	3,780	65	2700

20 This is the first such project to be led by Australia.
21 If the research is successful then plant yield gains are expected to be between 15 and 30 per cent.

	Australian production (million tonnes)	Value ($million)	World production (million tonnes)	Price per tonne ($)
Wheat	27	6,750	6711	250
Lentils	0.25	331	5	1325

SOURCE: FAO, USDA, FEDIOL & VARIOUS AUSTRALIAN SOURCES – LATEST AVAILABLE YEAR - SOME FIGURES ARE ESTIMATES

A.3.5 Adoption

If this SIEF project is successful, the adoption of its outcomes will take some years. If the Gates Foundation apomixis project is successful, the research team estimates that it might take another ten years before those outcomes are adopted. The take up of this technology will require regulatory approval.

If the SIEF heterosis work is successful, adoption could begin in five years. The adoption of the heterosis work is not subject to regulation.

In both cases we assume that the uptake will increase relatively fast to 50% of the Australian market and around 30% of the market in the rest of the world. It could be five years before take-up starts in Australia and ten years before it starts in other parts of the world.

A.3.6 Impacts

The potential impacts of the SIEF Plant Breeding project are significant and wide ranging.

There are possible economic impacts for farmers around the world, for seed companies and for CSIRO and its partners. Farmers would benefit from returns on higher yields and from the ability to use last years' crop as a source of seed, the seed companies could be able to provide growers with reliable new hybrids and the research organisations could receive payments from the seed companies.

There are also environmental benefits. These include reduced pressure on available arable land and water supplies, reduced use of agricultural chemicals and reduced pollution of rivers.

The social benefits include greater social stability from being able to better meet the food needs of the World's population. Food security would improve as farmers would be able to grow the same amount of food on a smaller area of land that required less water or fertiliser. They would also be able to collect seed from one year's crop to use for planting the next year's crop. This is particularly important in poorer regions where farmers cannot afford to buy new seed every year.

ACIL Allen has not sought to value the environmental or social benefits.

A.4 Clarifying the Impacts

A.4.1 Counterfactual

Had SIEF funding not been provided, it is unlikely that this research would have proceeded. Certainly the work would not have been able to reach the stage where it is today. While other groups have shown interest in this field, some leading researchers had considered what has been done as not achievable. In Australia, CSIRO was uniquely placed to undertake this research. Its work in plant biology is highly regarded and viewed as world leading. This is clearly demonstrated by the significant number of new collaborations generated by this project, particularly the funding provided by the Gates Foundation.

A.4.2 Attribution

At this stage, the research results from this project are attributable to 100% to SIEF. However by the time they are adopted there will have been contributions from the partners in the Gates Foundation project and possibly from other researchers and seed companies.

We propose to attribute 25% of the outcomes from this project to SIEF.

A.5 Evaluating the Impacts

A.5.1 Cost-Benefit Analysis

Costs

As noted above, SIEF funding for the project was: $1.208 million (2011-12), $1.806 million (2012-13), $1.724 million (2013-14), $0.606 million (2014-15) and $0.881 million (2015-16).

Benefits

As discussed earlier, the current value of rice, canola, sorghum, wheat and lentils production in Australia is $16.63 billion. The production of these crops are assumed to grow in value by 1% year in real terms in the absence of the SIEF-funded research (the Base Case).

The SIEF-funded research is assumed to increase the value of crop production by 6% in 2021-22 relative to the Base Case, 7% in 2022-23, 8% in 2023-34 and so on, until the increase tops out at 15% in 2031-32. Thereafter, the increase relative to the Base Case is assumed to remain constant at 15%.

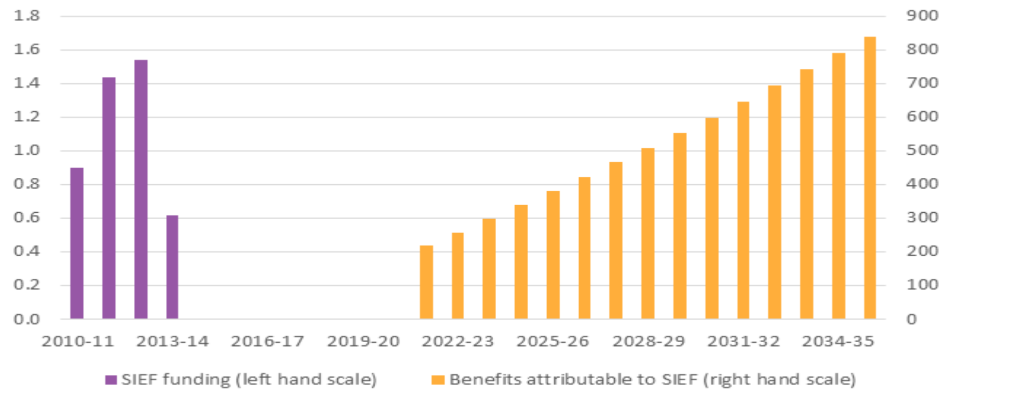
The increases from 2021-22 to 2025-26 are assumed to result from the apomixis research, while the increases from 2026-27 to 2030-31 are assumed to result from the heterosis research.

It is assumed that 25% of the increased value off crop production is attributable to SIEF.

Assessment of benefits against costs

The costs and benefits of the project to 2035-36 are shown in the figure below. The SIEF funding levels correspond to the left-hand scale while the annual benefits correspond to the right-hand scale.

FIGURE A.2 PLANT BREEDING PROJECT COSTS AND BENEFITS BY YEAR TO 2035-36 ($M, 2016-17 DOLLARS)



SOURCE: ACIL ALLEN

The present value of SIEF funding is $6.2 million in 2016-17 dollars under a 7% real discount rate. The present value of all project benefits is $2,825.3 million in 2016-17 dollars under the same discount rate.

The net present value (NPV) of the project is therefore $2,819.1 million in 2016-17 dollars under a 7 % real discount rate. The benefit-cost ratio (BCR) of the project is 459.5.

Sensitivity analysis

The BCR of the project:

— rises to 528.53 if the value of crop production in the Base Case increases by 2% a year instead of 1% a year

— rises to 488.17 if the increase in the value of crop production relative to the Base Case continues to grow beyond 2030-31 (specifically, the increase grows from 16% in 2031-32 to 20% in 2035-36).

A.5.2 Potential future impacts

As noted above, the impacts could start in Australia in five years and in ten years for the rest of the world. The ability to increase the amount of crop produced could have a major impact on the world's food supply. This could be particularly important in areas suffering from food shortages.

A.5.3 SIEF's role as an Innovation Catalyst

New agreements with GIFS Canada (University of Saskatchewan) for work on lentils and the collaboration and in-kind support from Professor Wu at the University of Sichuan, China, on applying this technology to rice will expand the possible use of the technology to other crops.

The support from the Bill and Melinda Gates Foundation for a five-year $US 22 million CSIRO-led project involving a total of seven international institutions including Pioneer DuPont provides a strong signal of the significance that the Foundation and the other institutions attach to the results of the apomixis research supported by SIEF.

A.5.4 Distribution effects on users

This project could create significant markets for seed producers.

A.5.5 Externalities or other flow-on effects on non-users

This could bring significant benefits to farmers, particularly poorer ones farming in areas of the world which are more marginal for production.

B

CASE STUDY: DISTAL FOOTPRINTS

BOX B.1 DISTAL FOOTPRINTS - EXECUTIVE SUMMARY

Key findings

The main areas of benefit that may arise for the Distal Footprints Research Project are:

- Information that can provide a catalyst for mineral exploration in unexplored areas by providing precompetitive (basic) geoscientific data.
- Information that can allow future explorers to apply new techniques and technologies to areas where mineral detection and extraction has previously been deemed too technically difficult or not cost effective enough to warrant investment.
- Access to information that can improve the way mine sites are closed and old or unused sites are remediated.

Innovation impact

The Distal Footprints project has developed an innovative approach that could allow resource discovery rates to increase significantly even in areas where the cover over the top of the potential source is relatively deep.

This case study uses the evaluation framework outlined in the CSIRO Impact Evaluation Guide. The results of applying that framework to the Distal Footprints case study are summarised in **Figure B.1**.

B.1 Purpose and audience for case study

This case study describes the economic, environmental and social benefits arising from the Science and Industry Endowment Fund (SIEF) research project “The Distal Footprints of Giant Ore Systems: UNCOVER Australia Project (RP04-063)”. The stated objectives of the Distal Footprints project are to:

- *Build on current knowledge to deliver improved understanding of the evolution and controls on mineral systems in the Capricorn region, with generic learnings that can be applied elsewhere to boost exploration discovery success in covered terrains in Australia.*
- *Provide a framework for establishing and applying an exploration 'toolkit' for the detection of distal footprints associated with mineral systems under cover. The toolkit will include a first order approach to cover, delineating its thickness, sampling the cover and revealing its complexity. It will include an understanding of the deeper crustal architecture in the region and the metallogenic potential of the broader mineral system in the crust and finally a mineralogical analysis approach within the toolkit that might detect a distal footprint of the*

expression of a potentially mineralised mineral system and better understanding of what anomalism means against the regional background.

– *Develop an Exploration Guide to the Capricorn region of Western Australia as a product for Junior Exploration companies and geologists.*
– *Develop a set of integrated large scale geological and geophysical datasets that assist with providing constraints on crustal whole lithosphere architecture and tectonic evolution.*

Funding Agreement between SIEF and the CSIRO, the University of Western Australia, Curtin University and the Geological Survey of Western Australia, 2013, Section B.3.

FIGURE B.1 DISTAL FOOTPRINTS CASE STUDY – IMPACT FRAMEWORK DIAGRAM

INPUTS	ACTIVITIES	OUTPUTS	OUTCOMES	IMPACTS
– SIEF investment (cash) – Financial (cash) support from research partners – In kind support from research partners – Financial support (cash) from industry partners	– Field and laboratory research – Research collaboration between researchers and funding partners	– Results of research – Publications – Conference papers – Opportunities for early career researchers – Training of PhDs – Publicly available geological survey data	– Improved productivity and competitiveness of research funding partners – Avoided exploration and remediation costs	– Avoided costs – Increased international trade? – Employment growth – Contribution to GDP?

SOURCE: ACIL ALLEN

This case study provides information for accountability, communication and continual improvement purposes. Its considers the impact of the Distal Footprints project from two perspectives: 1) against the objectives set for the project; 2) the other or unintended benefits that may have been generated from the project's inputs, activities, outputs and outcomes. The audiences for this case study may include Members of Parliament, Government Departments, SIEF, CSIRO, other research partners and the general public.

B.2 Background

Most of the large ore deposits found in Australia have been discovered as a result of their direct surface expression. However, two thirds of the continent and the potential ore bodies contained therein are under cover and the signs of any ore bodies are therefore hidden. This represents both a huge opportunity and a challenge for explorers and the nation. The technical risk associated with Australian mineral exploration due to this cover is reducing investment in Australia by major mining companies. At the same time, the difficulty in obtaining capital to finance exploration coupled with low levels of IPO activity for junior explorers means a reduced discovery success rate.

The mineral discovery success rate for high quality ore bodies is declining. If we are to replace the mineral resources already being extracted this decline must be stopped and then reversed.

New discoveries will sustain and drive export revenue, regional development, employment, royalty and taxation returns and a thriving mineral industry for the benefit of all Australians.

The key to the discovery of new high grade mineral deposits is the ability to detect and recognise the distal footprints ore bodies. The Federal government has called for a National Exploration Strategy to reverse the decline in greenfield exploration in Australia and drive improved discovery rates for new resources. The existing non bulk mining resource base in Australia has a relatively short future lifespan and yet new mineral resources are not found to replenish those being depleted. The Academy of Science High Flyers Think Tank and UNCOVER initiative has highlighted this and is encouraging exploration geoscientists to collaborate to tackle this national challenge with focussed research programs that will provide the science and toolkit to assist the industry.[22]

The Distal Footprints project aims to develop a toolkit with a workflow to identify such footprints within the hosting mineral system and thereby address a fundamental limitation in current exploration methodologies.

B.3 Impact Pathway

B.3.1 Project Inputs

Table B.1 shows the cash and in-kind support provided for the Distal Footprints project by the various contributors to the research. SIEF was the major cash contributor to the project with a total of $4 million. The project received strong support from the Geological Survey of Western Australia (GSWA), which contribute $2.5 million.[23] Industry also provided cash support of $900,000 for the research. Total cash support was $7.4 million.

In-kind support (provided by CSIRO, Curtin University and the University of Western Australia) totalled just over $6.1 million.

Note that the cash and in-kind support listed in **Table B.1** was used to fund work streams 1, 2, and 3.

TABLE B.1 CASH AND IN-KIND SUPPORT FOR THE DISTAL FOOTPRINTS PROJECT

Contributor / type of support	2012-13	2013-14	2014-15	2016-17	2017-18	2016-17	Total
Cash							
SIEF	$256,031	$928,407	$995,355	$1,007,020	$405,567	$407,620	$4,000,000
GSWA		$1,500,000	$500,000	$500,000			$2,500,000
Industry		$225,000	$225,000	$225,000			$900,000
Sub-Total							**$7,400,000**
In-kind							
Curtin	$105,145	$482,052	$502,240	$523,437	$242,239	$243,466	$2,098,579
UWA	$201,289	$362,489	$427,026	$447,269	$233,671	$234,854	$1,906,598
CSIRO	$143,492	$553,879	$587,096	$571,905	$113,350	$113,925	$2,143,440
Sub-Total							**$6,148,617**
Total Investment	**$13,548,617**						

Note: GSWA—Geological Survey of Western Australia

SOURCE: CSIRO

22 The UNCOVER initiative identified the Distal Footprints project as “a flagship research exemplar”

23 The funding from GSWA was used to carry out an airborne geomagnetic survey of the Capricorn region.

B.3.2 Project activities

The core activities of the Distal Footprints project fall into one of six work streams. Themes 1, 2 and 3 commenced in 2013 following the project's successful application for SIEF grant funding. These themes comprised the following research activities:

1. Theme 1 - Mineral Systems. This theme is aiming to examine the whole mineral system. It is studying the region at a very large scale and trying to build an image what is present at deep to intermediate depths. Researchers are using passive seismic techniques and magnetotellurics[24] to better understand the Capricorn mineral system in the context of the 4D evolution of the region.[25] [26] The work on this theme provides the framework that underpins the research on all the other themes.
2. Theme 2 - Characterising the cover in the Capricorn region. The researchers in this theme are using the results of the airborne survey to build a map of the approximately top 300 meters of the cover. This effectively provides a map of the subsurface and allows the researchers to identify where the cover is depositing or eroding. This in turn helps to determine the significance of what is detected at the surface. In other words, is the signature seen at the surface from below or from a more distant region?
3. Theme 3 - Mineral hosts as Distal Footprints. This theme is seeking to answer the question—what are the distal footprints associated with mineral deposits? The project will develop a 'distal footprints toolbox', to be applied to exploration in the Capricorn region. To do this the researchers are developing a better understanding of how key indicator trace elements can be associated with different ore deposit types at different distances from the sampling site. The research for this theme is applying techniques that have never before been used for mineral exploration.

Following the successful progress of these themes against the milestones established by SIEF and the project's funding partners, three additional research themes were adopted to build on the work already done. Work on these new themes was funded by the Minerals Research Institute of WA (MERIWA), the research partners and the Geological Survey of WA.[27] These themes were:

4. Theme 4 - The hydrogeochemistry of the Capricorn. This theme seeks to map the hydrogeochemistry of specified areas within or adjacent to the Capricorn region and determine background concentrations of elements with exploration importance for different mineral types. The research will also examine the detection of different isotopes in groundwater or can be used to analyse the prospectivity of an area
5. Theme 5 - Geochemical Mapping for Lithospheric Evolution, Metal Reservoirs & Predictive Targeting. This theme seeks to undertake:
   - Zircon separation (SELFRAG LAB) using selective fragmentation and recovery of morphologically intact zircon
   - Zircon characterisation using SEM analysis and CL imaging
   - LASS-ICPMS analysis using simultaneous U-Th-Pb and trace element abundances.
6. Theme 6 - Developing a Digital Model using virtual environments for data integration and visualisation. This theme seeks to provide a standardised approach to data management (i.e. sample data, analysis data) to make it easier to both disseminate data to end users and to provide end users with analytical and visualisation tools to enable them to more easily make use of the data.

ACIL Allen's consultations with project leaders made it clear that, while themes 4—6 are not formally funded by SIEF, there is a high level of interaction between all the research themes under the Distal Footprints project. That is, the learnings and data generated from one research theme influences the activities of the other research themes.

[24] Magnetotellurics is an electromagnetic geophysical method for inferring the earth's subsurface electrical conductivity from measurements of natural geomagnetic and geoelectric field variation at the Earth's surface.

[25] Orogens develop when a continental plate is crumpled and is pushed upwards to form mountain ranges. The geological processes involved are collectively called orogenesis.

[26] The choice of the Capricornia region was driven by a number of factors. These included that GSWA had recently conducted a seismic study of the region, the region was surrounded by some good infrastructure and that the region was of interest to a number of smaller explorers.

[27] SIEF did not provide any funding support for research themes four, five and six.

B.3.3 Project outputs

Research outputs

The Distal Footprints' core research team have been actively seeking to publish their research findings and contribute to the growth of the stock of knowledge about exploration methodologies and techniques. The table below provides a list of publications (and submissions) by Distal Footprints-supported researchers since 2014.

TABLE B.2 PUBLICATIONS ASSOCIATED WITH THE DISTAL FOOTPRINTS PROJECT

Year	Authors	Title	Journal	Status
—	White, A.J.R., Pearce, M.A., Meadows , H.R	Distinguishing regional and local scale metasomatic systems at the Prairie Downs ZnPb deposit.	LITHOS	In review
—	Devaraju A., Klump J., Cox S. J. D., and Golodoni uc P	The Internet of Samples: Representing and publishing physical sample descriptions	Computers & Geosciences	In review
2014	White, A.J.R., Smith, R.E., Nadoll, P., leGras, M	Regional scale metasomatism in the Fortescue Group volcanics, Hamersley Basin, Western Australia: Implications for hydrothermal ore systems.	Journal of Petrology 55, 977-1009	Published
2014	White, A.J.R., leGras, M., Smith, R.E., Nadoll, P.	Deformation-driven, regional scale metasomatism in the Hamersley Basin, Western Australia	Journal of Metamorphic Geology 32, 417-433	Published

SOURCE: DISTAL FOOTPRINTS PR3 PROGRESS REPORT TO SIEF

In addition, the Distal Footprints project researchers have been active in the dissemination of research findings at national forums. Over the past two years key Distal Footprints researchers have given 18 conference presentations. Four are listed below:

1. White, A.J.R., Pearce, M.A., Meadows, H.R., Treacy, J., Robinson, J. Geochemical background: A statistical approach to anomaly detection. Society of Economic Geologists, Hobart, Australia, September 2015.
2. White, A.J.R., Pearce, M.A., Meadows, H.R. Distinguishing local- and regional-scale metasomaticsystems. Australian Earth Sciences Convention, Adelaide, Australia, June 2016 (accepted)
3. Golodoniuc P., Klump J., Reid N., and Gray D., 2016, Mobile field data acquisition in geosciences: Geophysical Research Abstracts, Vol. 18, pp. EGU2016-1566, Copernicus Society, Vienna, Austria.
4. Golodoniuc P., Devaraju A., and Klump J., 2016, The implementation of IGSN in the context of Australian mineral exploration: Geophysical Research Abstracts, Vol. 18, pp. EGU2016-1562, Copernicus Society, Vienna, Austria.

Research training and early career development

Distal footprints has provided career development and research training opportunities for a number of researchers in Western Australia. Each of these researchers have made a positive contribution to the research output of the project and/or progress towards the completion of their doctorates. Details of the postdoctoral researchers and doctoral students directly funded by SIEF are provided in **Table B.3.**

TABLE B.3 EARLY CAREER AND DOCTORAL STUDENTS DIRECTLY SUPPORTED BY SIEF

Postdoctoral or research fellows	Research discipline/focus	Doctoral candidate	Research discipline
Dr Alistair White	Research scientist with the CSIRO Mineral Resources Flagship	Sasha Banaszczyk	PhD candidate working on a geophysical component of the Footprints project—University of Western Australia

Postdoctoral or research fellows	Research discipline/focus	Doctoral candidate	Research discipline
Dr Sam Spinks	Research geologist with experience in economic geology and Precambrian geological research	Vikraman Selvaraja	PhD candidate focusing on the mineralisation in the orogen and its relationship to the evolution of the orogeny in a spatial and temporal sense—University of Western Australia
Dr Diana Plavsa	Research Associate examining the tectonic evolution of the Capricorn Orogen—Curtin University	Holly Meadows	PhD candidate focusing on multi-stage ore formation
Dr Sandra Occhipinti	Senior Research Fellow Exploration Targeting—University of Western Australia	Inalee Jahn	PhD candidate in the Department of Applied Geology—Curtin University

SOURCE: DISTAL FOOTPRINTS PR3 PROGRESS REPORT TO SIEF

Publicly available exploration data

Where and when mineral exploration occurs depends on the perceptions of a region's geologic potential and the overall climate for the medium-to-large scale investment usually required to fund exploration activities. Perceptions of geologic potential are influenced by a number of factors, including:[28]

— First, perceptions reflect the knowledge about the region's geology obtained from previous activities, which can include previous exploration and mining, as well as non-mining activities such as road building and assessment of geological hazards.

— Second, the results of geoscientific research and information from publicly available geological surveys often play a critical role in attracting exploration to a relatively unexplored region, such as the Capricorn.

A key feature of the Distal Footprints project is that it contributes to the stock of precompetitive research results and data on the Capricorn region. These data can be described as a form of public good - that is, they are goods which are likely to be undersupplied by the market because they benefit the entire industry.

The information generated by the Distal Footprints project can provide a catalyst for mineral exploration in unexplored areas by providing precompetitive (basic) geoscientific data. That information can provide exploration companies with important signals that can point to the geological potential of the Capricorn. These signals can also be applied to other regions that display similar geological characteristics/formations.

The availably of the precompetitive data on the geology of the region generated from the Distal Footprints project also allows different explorers (using different techniques) to explore areas of the Capricorn which may have been previously examined and deemed unsuitable for development. History is littered with examples of deposits that have been discovered only after several exploration attempts have been made in the same area.

Furthermore, the availability of these data allow future explorers to apply new techniques and technologies to areas where mineral detection and extraction has previously been deemed too technically difficult or not cost effective enough to warrant investment.

Finally, a better understanding of the mineralisation could also inform decisions on how best to develop any resource that might be found.

[28] Roderick G. Eggert, Mineral Exploration Development: Risk and Reward, May 2010, http://www.miningnorth.com/_rsc/site-content/library/education/Mineral_Exploration_&_Development_Roderick_Eggert_Eng.pdf

Innovation / commercialisation

A WA firm (Lab West) that has been helping the research team with the analysis of samples have used their involvement in the project to drive a significant improvement in the efficiency of their operations—in particular, their exploration/sampling techniques.

B.3.4 Project Outcomes

Given the relatively short time since this project began it is likely to be some time before the outputs of the research generate outcomes. Nonetheless the early signs are encouraging, with one of the minor explorers, Marindi Metal, participating in the project pegging an area in the Capricornia region based on the information delivered to date by the research effort.

We also note that the results from the Distal Footprints project have provided GSWA with the confidence to decide to carry our airborne magnetic surveys in other parts of Northern Australia. The information gained from this and other surveys will be a long term national asset that can be repeatedly examined and analysed as the technology available to do so changes and improves.

Direct economic benefits of the Distal Footprints project will flow from the potentially increased economic activity generated by additional exploration activity that might result from the information generated by Distal Footprints project. Additional exploration is more likely to be seen from those companies which have supported the SIEF funded research as they have exclusive access to the research results for a period of time. However, other exploration industry players will also ultimately benefit from the publicly available knowledge generated by the research.

In essence, these benefits are the positive commercial outcomes that accrue to the exploration industry. They can take the form of increased chances of exploration activity that leads to the identification of new deposits that are economic to develop. There is also the prospects of improvements in the efficiency of exploration activities as companies get a better picture of the risks and opportunities of exploration in a particular region. The benefits could be reflected in avoided costs of exploration activities that do not reveal a commercially viable deposit.

There are also broader potential environmental benefits from improved characterisation of the Capricorn region. For example, the outputs from the Distal Footprints project have potential to improve the way mine sites are closed and old or unused sites are remediated. Improved characterisation provides important insights about the way mineral deposits form within a region and waste or hazardous materials below the earth's surface are distributed over a long term timeframe.

The results from Theme 2 of the research are also expected to be useful for water discovery.

Additional detail about the impacts (or benefits) generated from these outcomes is provided in Section B.3.6.

B.3.5 Adoption

It is still very early in the life of this project and therefore there has not been a great deal of adoption of the results of the research. However there are a number of extremely promising early signs that the benefits of this project will be considerable. They include:

— The decision by MERIWA to extend the scope of the project by providing significant funding for themes 4 to 6 of the project.

— The decision by Marindi Metal to pick up a mining tenement in the Capricornia region after receiving the early results of the analysis carried out.

— Marindi Metals have reported that their tenement activity has doubled following their involvement in the Distal Footprints project.

— Another firm is reportedly also considering acting on the information provided by the project.

— The Deep Exploration Technologies CRC has announced their intention to use the outputs of the project.

There are few, if any, barriers to the adoption of the technologies being developed. ACIL Allen is therefore confident that if the exploration results from early adopter firms like Marindi Metals are successful then the adoption rate of the technology among the rest of the industry is likely to be very rapid.

B.3.6 Impacts

Current impacts

Impacts on the operations of industry partners

The Distal Footprints program has generated some commercial benefits for the businesses which have supported the project.

Future potential impacts

De-risking the exploration process—avoided costs

Mineral exploration and development are, by definition, speculative activities. The rewards for successful exploration can be significant if a mineral deposit is discovered and developed into a commercial mining operation. For an exploration and mining company, successful exploration can lead to increased profits. For a State Government, successful exploration can lead to jobs that otherwise would not have existed; to investment in local infrastructure (e.g. roads and power generation), and to increased government revenues.

But mineral exploration also carries with it risks and potentially high costs. Mining companies invest in exploration in the expectation that future revenues will be sufficient to cover the upfront costs of exploration and deliver an acceptable profit to shareholders in the future. The level and location of investment are determined by expected revenues and costs, adjusted for time and risk. For example, the higher the expected revenues or the lower the expected costs, the more attractive an investment opportunity is.

The factors that influence expected revenues, costs, and risks in the mining sector have been grouped into four categories by US academic Roderick G. Eggert:[29]

— *Geologic Factors*—Does a mineral resource exist in a region, in what quantities, and of what quality? Geologic risk can be conceptualised as the likelihood and degree to which actual mineralisation (its quantity and quality) differs from what is anticipated at the point a decision is made to undertake exploration.

— *Technical Factors*—Can a known resource be extracted and processed with existing or likely future technologies? Technical risk can be conceptualised as the likelihood and degree to which actual recovery of a mineral during mining and processing differs from what was anticipated.

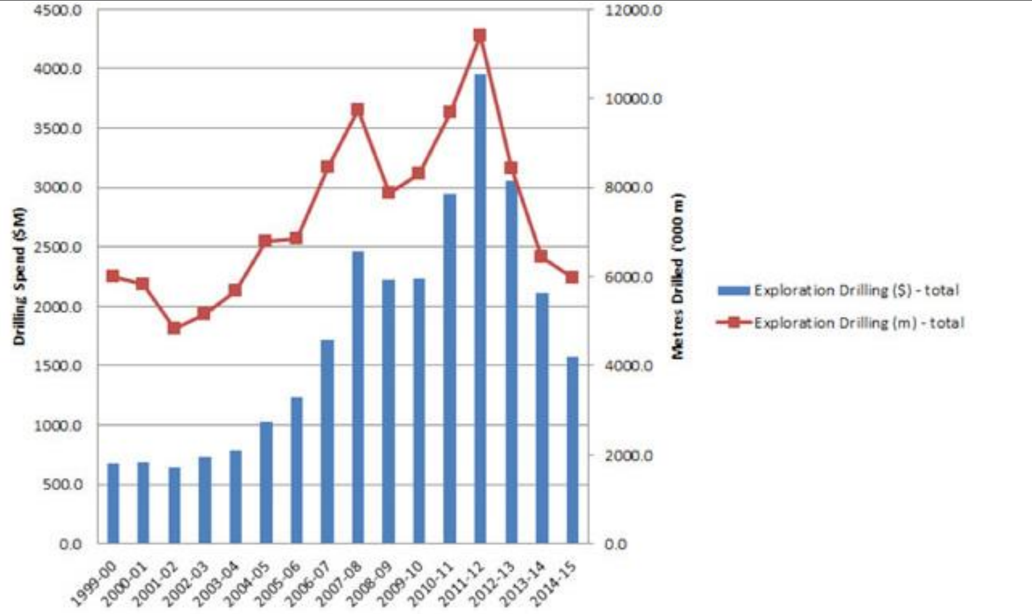
— *Environmental, Social, and Political Factors*—Can a resource be extracted in ways that are consistent with a nation’s preferences and policies for environmental protection?

— *Economic Factors*—Overall, can a mineral resource be extracted at a profit? Economic risk can be conceptualised as the degree to which actual revenues and costs differ from what was anticipated at the time of investment? Economic risk reflects the three other categories of risk cited above.

ABS data shows there has been a continuing decline in minerals exploration in Australia. While there has been a small recent upturn in the overall level of exploration activity and expenditure, the long term data shows current activity is at levels last seen in the mid-2000s (see **Figure B.2** below). It is clear from the consultations undertaken for this case study that this decline is both a function of the perceived risks of exploration activity in Australia (and in particular in previously unexplored (or very lightly explored) regions, such as the Capricorn), and the high costs of exploration activity.

[29] Roderick G. Eggert, Mineral Exploration Development: Risk and Reward, May 2010, http://www.miningnorth.com/_rsc/site-content/library/education/Mineral_Exploration_&_Development_Roderick_Eggert_Eng.pdf

FIGURE B.2 ANNUAL AUSTRALIAN EXPLORATION ACTIVITY (EXPENDITURE AND METERS DRILLED)



Note: Based on ABS data

SOURCE: MINERALS COUNCIL OF AUSTRALIA, HTTP://WWW.MINERALS.ORG.AU/POLICY_FOCUS/EXPLORATION/

Australia requires an expanded exploration effort to improve its standing as a destination for investment and to ensure the ongoing development of mining projects, which generally have a gestation period of around ten years and a productive lifetime of ten-to-fifteen years.

Data produced by the Mineral's Council of Australia (MCA) shows that over the past 20 years Australia's share of economically significant mineral discoveries has declined significantly. These data show that Australia's share of global exploration for non-fuel mineral commodities has declined from 17.6% in 2002 to 12% in 2014.[30]

These data further show that exploration expenditure continues to be in sharp decline. Exploration expenditure fell 25.3% in 2014-15 to total $1.575 billion, which is a decline of 48.5% from 2012-13 and down 60.2% from 2011-12. Western Australia continues to account for the largest share of total exploration expenditure (about 58%) followed by Queensland (almost 20%). However, these data also indicates that Australia's attractiveness as a destination for mining investment is declining with it falling further behind major competitors Canada and the United States.

The information, techniques and technologies generated by the Distal Footprints project is anticipated to provide the knowledge required to de-risk exploration and, over time, reduce the costs of exploration. The six research themes of the Distal Footprints research project is leading to advances and expertise in detection technologies, mineral systems, resource characterisation and data analysis. This in turn supports more cost effective exploration and discovery of new mineral resources in the, to date relatively lightly explored, Capricorn region.

Analysis by ACIL Allen in 2015 for the Western Australian Government identified some key parameters that can help us to estimate the potential value of exploration.[31] The analysis considered drilling data between January 2012 and November 2014 for Western Australia. These data show that there were 40,187 mineral exploration holes drilled across the State with a combined distance of approximately 4 million meters of drilling. Based on analysis of ABS data (catalogue 8412) ACIL Allen estimated that the average cost of drilling for a new deposit to be $382 per meter.

30 http://www.minerals.org.au/policy_focus/exploration/

31 *Exploration Incentive Scheme: Economic Impact Study*, Report to the Geological Survey of Western Australia, ACIL Allen, 2015.

Based on these calculations, any improvement to the accuracy and effectiveness of exploration would reduce the economic burden of exploration by the value of the avoided meters of drilling. If even a small proportion of the 4 million meters drilled between 2012 and 2014 were avoided, say for example, 1% (i.e. 40,000 meters), this would generate an economic benefit (through avoided costs) of $15.28 million.[32]

Remediation of old (unused) mining sites

Australia has more than 50,000 abandoned, unused or legacy mining sites. These sites can range from a shallow excavation, costean or shaft to a major mining legacy site such as Mt Morgan in Queensland, Redbank in Northern Territory, Mt Lyell in Tasmania or numerous other less well documented sites in New South Wales, South Australia and Western Australia.

Depending on the size and seriousness of impact, old mines can be a risk to human safety and the environment. Traditionally some jurisdictions may have focused more on human safety and adopted a narrow approach to remediation which included boarding up shafts and fencing open cuts. As the mining industry and government's understanding of on-site impacts grow, so has the recognition that there are many off-site cumulative and perpetual impacts associated with legacy mining sites.[33]

Distal Footprints provides data and characterisation techniques that help mine operators and authorities to better understand the geological characteristics of the mine site and surrounding areas. These data and techniques can be used to model (and eventually anticipate) how the different geodynamic settings of the Capricorn mineral system (Theme 1) might influence the dispersion of environmentally damaging materials following the closure of a mine site. They can also be used to better understand how the geodynamic settings of a mine site might disperse minerals and materials that impact the health of communities within mining regions.

In 2003, the Western Australian Government published an inventory of legacy mines, noting some 88,000 mining legacy features such as tailings, waste rock dumps, open cut and shafts. The Mining Rehabilitation Fund (MRF) was developed and implemented in 2013 in response to a potential increase in the unfunded rehabilitation liability for abandoned and historical mines in Western Australia.[34] The MRF raises money through a non-refundable mining levy on new miners, calculated on the basis of size of the disturbance area and the risk and level of impact of the new mining operation. All tenement holders operating on *Mining Act 1978 (Mining Act)* tenure (with the exception of tenements covered by State Agreements not listed in the regulations), are required to report disturbance data and contribute annually to the fund. Tenements with a rehabilitation liability estimate (RLE) below a threshold of $50,000 must report disturbance data but are not required to pay into the fund.[35]

In 2015, the MRF reported the fund held approximately $60 million, which included approximately $1.95 million in interest earned by the fund.[36] The MRF has collected approximately $27 million a year from liable entities over the last two years. With the ongoing development of the Distal Footprint research it may be possible to, over time, improve our understanding of the sub-surface environment and its impact on old mine sites. This improvement may assist geologists and environmental scientists to develop new and improved remediation techniques that reduce the cost and long term economic burden of remediation. It may be possible to allocate resources currently earmarked for remediation to more productive activities, such as additional exploration, extraction and production improvements.

If the research outcomes of Distal Footprints could be used to reduce the costs of remediation in Western Australia by say 5%, then the annual contribution to the MRF by liable parties could be

32 ACIL Allen 2015, 'Exploration Incentive Scheme: Economic Impact Study', Report to the Geological Survey of Western Australia.

33 Pepper, M., Roche, C.P and Mudd, G.M., 'Mining Legacies—Understanding Life-of-Mine Across Time and Space', Life-of-Mine Conference, Brisbane, 16-18 July, http://www.mpi.org.au/wp-content/uploads/2013/12/Pepper-Roche-Mudd-2014-Mining-Legacies-copy.pdf

34 Department of Mines and Petroleum 2015, 'MRF Yearly Report 2015', http://www.dmp.wa.gov.au/Documents/Environment/MRF_yearly_report_2015.pdf

35 Department of Mines and Petroleum, 'What is the MRF?', http://www.dmp.wa.gov.au/Environment/What-is-the-MRF-19522.aspx

36 Department of Mines and Petroleum 2016, 'Western Australia's Abandoned Mines Program', Goldfields Environmental Management Group Workshop 2016.

reduced by an equivalent proportion. This would lead to an economic saving of approximately $1.35 million a year for the mining companies operating in the State.

B.3.7 Counterfactual

A research project of this scale and scope would not have been possible without the funding and support of SIEF.

Prior to SIEF, the University of Western Australia, Curtin University and the CSIRO had collaborated on a number of occasions. However, these collaborations were often at the researcher level and commensurate to the size of the research funding opportunities available through the competitive grants system, or through small-scale state government, industry or university-supported funding programs. Funding for these projects was often piece meal, short term and not of sufficient scale to adequately fund a multi-year, multi-institutional project to deliver the human capital and research infrastructure needed to deliver the SIEF project objectives.

So, while some useful research outputs and outcomes were generated through these earlier collaborations, the scale of the effort needed to effectively examine the Distal Footprints of the Capricorn region and deliver the research outputs needed to improve exploration in the region would have been impossible without access to the SIEF funding.

Consultations with the project's research leaders undertaken confirmed the central role of SIEF in establishing the project. SIEF provided the level of funding necessary to encourage CSIRO, the University of Western Australia and Curtin University to enter into discussions about a large scale collaboration in geoscience research in Western Australia. Importantly, the funding also provided an incentive for the State Government to not only participate in, but also to contribute significant financial and in-kind support to the research effort.

Participating research institutions were also able to more effectively demonstrate their commitment to a large scale research project that would deliver benefits to industry. The presence of SIEF funding made the prospect of a research project 'more attractive' by increasing the likelihood that industry partners would receive 'actual' as opposed to 'promised' benefits from their financial support.

B.3.8 Attribution

Consultations undertaken for this case study suggest that the attribution of Distal Footprints' benefits to SIEF should be high. This is because the participants in the project are firmly of the view that a project with the scope and scale of Distal Footprints would not have been possible in the absence of SIEF funding support. In ACIL Allen's professional opinion a high level of attribution may be appropriate for those benefits (and beneficiaries) that are more closely aligned to the research effort and outputs.

Other beneficiaries (such as non-participating industry end-users of open source data from the Distal Footprint project) may be subject to a range of other factors which are beyond the reasonable influence of SIEF. Hence, it may be appropriate to attribute any benefits they receive to SIEF at a lower rate.

Generally, a conservative attribution rate has been adopted for this case study to ensure the benefits generated by SIEF's support for the Distal Footprints project is not overstated.

B.4 Evaluating the Impacts

B.4.1 Cost-Benefit Analysis

Costs

SIEF funding for the project was: $0.741 million (2011-12), $1.425 million (2012-13), $1.397 million (2013-14), $1.444 million (2014-15), $0.393 million (2015-16) and $0.600 million (2016-17).

Benefits

De-risking the exploration process

In the period from early 2012 to late 2014, on average approximately 1,411 million metres of mineral exploration holes were drilled in Western Australia every year. The average cost of this drilling was $382 per metre.

It is assumed that the SIEF-funded research results in miners having access to information that allows them to more accurately target their drilling activities and that this results in a 1% reduction in the distance drilled per year from 2021-22 onwards, and that 50% of these benefits are attributable to SIEF.

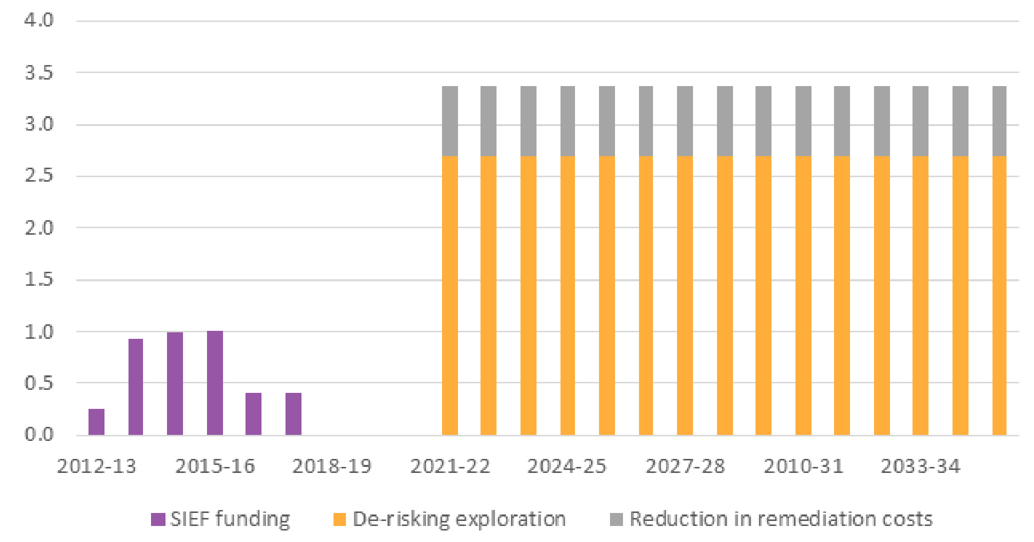
Remediation of old (unused mine sites)

As discussed previously, the annual cost of mine remediation in WA is approximately $27 million. It is assumed that the SIEF-funded research enables a 5% reduction in WA's annual mine remediation costs from 2021-22 onwards, and that 50% of these benefits are attributable to SIEF.

Assessment of benefits against costs

The costs and benefits of the project to 2035-36 are shown in **Figure B.3**.

FIGURE B.3 DISTAL FOOTPRINTS COSTS AND BENEFITS BY YEAR TO 2035-36 ($M, 2016-17 DOLLARS)



SOURCE: ACIL ALLEN

The present value of SIEF funding is $4.27 million in 2016-17 dollars under a 7% real discount rate. The present value of all project benefits is $23.43 million in 2016-17 dollars under the same discount rate.

The net present value (NPV) of the project is therefore $19.16 million in 2016-17 dollars under a 7% real discount rate. The benefit-cost ratio (BCR) of the project is 5.4.

Sensitivity analysis

The BCR of the project:

— Increases to 23.05 if the SIEF-funded research enables a 5% reduction in drilling distance per year in WA instead of 1%

— Decreases to 4.83 if the SIEF-funded research enables a 2% reduction in annual mine remediation costs in WA instead of a 5% reduction.

B.4.2 Potential future impacts

While the results of the Distal Footprints project will initially be applied in WA, there is the potential for them to over time be applied across parts of Australia.

B.4.3 SIEF’s role as an Innovation Catalyst

The Distal Footprints project is an innovative approach that could allow resource discovery rates to increase significantly even in areas where the cover over the top of the potential source is relatively deep.

B.4.4 Distribution effects on users

The main beneficiaries of this research are likely to be mining firms.

B.4.5 Externalities or other flow-on effects on non-users

There may be some environmental benefits as a result of being better able to manage the remediation of mining sites.

C

CASE STUDY: EARLY NUTRITION

BOX C.1 EARLY NUTRITION - EXECUTIVE SUMMARY

Key findings

This project has three possible impact and benefit streams:

— Addressing deficiencies in the nutrition provided to ewes before conception and during pregnancy may have a critical impact on the survival rates of newborn lambs.
— A successful test for identifying a patient's risk of obesity and an important tool for monitoring the impact of treatment regimes in at risk persons.
— In the longer term it may be possible to develop a test for newborns that provides an indication of the child's predisposition to obesity.

Innovation impact

The early nutrition project has enabled potential innovation in a number of areas. For example:

— The ability to connect the results from the human obesity research to CSIRO's existing work in the field of diet could potentially lead to new products or services for persons battling obesity.
— The research on sheep epigenetics could very significantly accelerate the genetic selection of breeding animals. This was an unexpected consequence of the research.
— The partnership with an agricultural firm to trial the application of the research outputs for decreasing lamb mortality demonstrates the level of trust between industry and CSIRO, which helps to catalyse innovation.

This case study uses the evaluation framework outlined in the CSIRO Impact Evaluation Guide. The results of applying that framework to the Early Nutrition case study are summarised in **Figure C.1**.

C.1 Purpose and audience for case study

This case study describes the economic, environmental and social benefits arising from SIEF's funding for research project Early Nutrition, the Epigenome and the Prevention of Disease (EpiSCOPE) (SIEF project identifier: RP03-064).

This information is provided for accountability, communication and continual improvement purposes. Audiences for this report may include Members of Parliament, Government Departments, SIEF, CSIRO, other researchers and the general public.

FIGURE C.1 EARLY NUTRITION CASE STUDY – IMPACT FRAMEWORK DIAGRAM

INPUTS	ACTIVITIES	OUTPUTS	OUTCOMES	IMPACTS
– SIEF investment – In-kind support from CSIRO, Garvan, WCHRI and University of SA	– Research – Testing	– Research results – New research collaborations	– Partnership(s) with business – Potential new products and services	– Potentially: – more sustainable farming – improved environmental and social outcomes – improved population health – employment growth – contribution to GDP

SOURCE: ACIL ALLEN

C.2 Background

Diseases such as type 2 diabetes, obesity, heart disease and stroke are in epidemic proportions in the developed world. The current direct health cost of obesity in Australia is over $8 billion a year. That cost is continuing to grow steadily. Environmental and dietary impacts in early life, including during pregnancy, have long term health outcomes and there is evidence of an intergenerational transmission of obesity, i.e. obese mothers have heavy babies who become obese in later life. The emerging thinking is that nutritional perturbations during early development alter the way in which information in the genome is read and utilised throughout life. This reading and remembering is controlled by a set of semi-permanent 'marks' on the genome, the *epigenome*. Understanding the molecular mechanisms through which early patterns of nutrition shape the developing epigenome is central to the challenge of trying to reverse the growing prevalence of lifestyle-related diseases.

To address this challenge, the EpiSCOPE project was established as a collaboration between CSIRO (at that time including 3 Divisions – Food & Nutrition, Livestock Industries and Mathematics and Information Sciences), the Garvan Institute of Medical Research, The Women's and Children's Health Research Institute (WCHRI) and the University of South Australia, with funding support from SIEF.

At the start of the project, evidence was accumulating that the nutritional environment during pregnancy could have profound outcomes on the health of children in later life. Data from animal systems, particularly in the mouse, had provided evidence that epigenetic changes arising in utero could be maintained into adult life with resultant long term health impacts on offspring. Obesity and metabolic health were significant among the measured impacts.

The EpiSCOPE project brought together a unique multi-disciplinary team to discover epigenetic signatures of later life metabolic traits which may be influenced by exposure to over nutrition in early life. The aim of the project is to develop early life risk predictors for adult lifestyle diseases which will help guide nutritional advice for mothers during pregnancy and dietary recommendations for reversing the programming toward better health outcomes.

The project set out to understand the role of epigenetics and the epigenome in the development of human obesity and metabolic disease by conducting research in three related areas, namely:

— *Component A*: Development of comprehensive epigenome and gene expression maps of adipocytes (fat cells) from obese and obese/diabetic people, in comparison to normal weight, healthy individuals.
— *Component B*: The impact of periconceptional maternal over-nutrition on the epigenome of adipose tissue in lambs (both in the livestock context and as a well-controlled model for human pregnancy)
— *Component C*: Epigenomic signatures in a Human Cohort: Assessing the impact of omega-3 fatty acid supplementation in pregnancy on the epigenome, and the relationship of the epigenome to child obesity and metabolic health measures.

The research in Component C was possible because the project had access to the results of a clinical trial in Adelaide that examined the impact of pre-natal nutritional supplements for pregnant women (specifically omega-3 supplements) on the health of newborns (the DOMInO study). This was the largest study of its kind in the world.

C.3 Impact Pathway

C.3.1 Project Inputs

The total cost for the three components of the EpiSCOPE project was around $17.8 million in cash and in-kind contributions. The SIEF contributed about $5 million (around 22% of the total cost), CSIRO contributed around $7.4 million (41%), the Garvan Institute contributed just under $1.9 million (10%), WCHRI contributed almost $2.3 million (13%) and UniSA contributed about $1.3 million (7%). The cash and in-kind support provided for the project is shown in **Table C.1**.

TABLE C.1 SUPPORT PROVIDED TO THE EARLY NUTRITION PROJECT

Contributor / type of support	2011-12	2012-13	2013-14	2014-15	2015-16	Total
Cash						
SIEF	$861,393	$1,377,814	$1,407,155	$529,005	$823,758	$4,999,125
In-kind						
CSIRO	$1,215,877	$1,940,574	$2,002,002	$931,550	$1,291,008	$7,381,011
Garvan	$293,540	$457,922	$476,239	$240,293	$387,063	$1,855,057
WCHRI	$589,987	$675,096	$685,899	$140,484	$198,954	$2,290,420
University of SA	$211,637	$316,154	$327,799	$169,956	$263,274	$1,288,820
Totals	**$3,172,434**	**$4,767,560**	**$4,899,094**	**$2,011,288**	**$2,964,057**	**$17,814,433**

SOURCE: CSIRO

C.3.2 Project activities

For Component A of the project the research team studied fat cells in obese and lean adult humans with the aim of identifying epigenetic differences that could be used as a diagnostic and or a monitoring tool in the prediction and treatment of obesity. If successful, the results could also potentially be used to tailor food industry products to assist with weight loss.

The research for Component B of the project identified genes and proteins involved in depositing white and brown fat in lamb foetuses and effects of maternal overnutrition around the time of conception.

The research for Component C of the project re-examined the results of a clinical trial in Adelaide that had examined the impact of pre-natal nutritional supplements for pregnant women. The research sought to identify methylation markers on the genome that could provide a sign that children might have an increased predisposition for developing obesity and or diabetes, and whether the mother's diet during pregnancy had an impact on those markers.

C.3.3 Project outputs

One of the initial aims of the project was to identify methylation markers on the genome that could provide a sign that children might have an increased predisposition for developing obesity/diabetes, and the impact of the mother's diet on those markers. The project's outputs can be grouped under three headings, findings that could lead to improvement in health outcomes for: livestock (initially sheep); adults, and children.

Livestock

The primary purpose for studying sheep was initially as a model for human pregnancy. However during the project the research team was able to identify genes and proteins involved in depositing brown fat in lamb foetuses.

As part of the research ewes were over-nourished for four months before conception, then the foetuses were transferred to ewes which had had normal levels of nutrition before conception. The research team found that the over nourishment of the biological parent ewes resulted in significant impacts on the organs of lambs that are involved in insulin signalling and identified a significant impact on epigenetic chromatin marks. A paper will be submitted to Nature Communications on the results of the research. (Note that this kind of research on humans would not be possible for ethical reasons).

The research also identified significant differences between brown and white fat in genes involved in iodine metabolism. This led to the hypothesis that dietary deficiencies in the trace elements Selenium (Se) and iodine (I) might be implicated in lower than optimal levels of brown fat in new born lambs. This research on sheep indicated that ewe nutrition before conception and during pregnancy may have a critical impact on the survival rates of their newly-born lambs and their later production characteristics.

Adult humans

The project undertook cross-sectional studies of fat cells in obese and lean adults. The aim was to identify differences in epigenetic markers on the genome (methylations) between lean and obese subjects.

The project showed that, in adults, there are strong and clear differences in the epigenetics of both visceral and subcutaneous fat cells between lean and obese individuals. It may be difficult to use this directly as a test as it can be challenging to sample subcutaneous tissues and fats. The aim would be to see if it is possible to develop a more easily applied form of test, such as a blood or buccal test that can provide similar information.

Importantly epigenetics tests can be used to identify medical attributes of individuals that are capable of being altered through intervention, whereas genetics tests provide information that is essentially immutable.

One of the important findings of the project was that it showed that non-fat cells (i.e. stem cells that were originally destined to become other (non-fat) cells) were being recruited to be part of the fat deposit in obese adults. However, this was not the case in lean adults. It is possible that this finding may help to explain some of the poor health outcomes for obese individuals. It also means that there might be the potential for these cells to be preferentially targeted (e.g. targeting cell markers or properties) in treatments of obese people.[37]

The research team produced the first such epigenetic data on visceral and subcutaneous fat deposits. A Swedish group in parallel identified that cells from bone marrow transplants were being captured to create subcutaneous fat cells. The two groups are now seeking to establish a collaborative research program.

A successful (and less invasive) test could be a very powerful tool in the identification of a patient's risk of obesity and also an important tool for monitoring the impact of treatment regimes. Such a monitoring tool would be very useful in encouraging patients to take action and in encouraging adherence to a treatment program and delivering better long term health outcomes.

37 The research team is seeking funding to continue this work.

The cost to the economy of obesity and other illnesses where obesity is a contributing factor is substantial. Therefore, any measure to reduce the incidence of obesity could potentially have large benefits.

Children

The project sought to identify methylation markers in children that identify a higher risk of obesity across their lifespan and also those that differed in children that had been supplemented, or not, with Omega-3 fatty acids during the second half of pregnancy. The epigenome-wide data and health measures were collected on children from a large South Australian clinical trial (the DOMInO study)

This is the largest nutrition intervention trial in humans to have examined the effects on the epigenome – while the effects seen were small, it points to the need to understand the impacts of nutrition earlier in pregnancy, where effects might be much larger.

The project found that there is only a relatively weak correlation between the epigenetic markers of infants and their propensity to suffer from obesity. There is at most a 5 % difference in DNA methylation marks at any specific sites of infants who are in the top and bottom quartiles of obesity at 5 years of age.

Innovation / Commercialisation

The researchers on this project are exploring a possible partnership with a commercial firm to further investigate how the project outputs relating to livestock could be used to improve lamb survival rates.

The capability developed by researchers (including 2 new postdoctoral fellows) over the course of this project is being applied in a program linking nutrition and genetics in personalised diet advice. Researchers are currently talking to private sector firms about the potential to include a genetics element in diet advice (potentially linking in with the CSIRO’s on-line diet publication).

Collaboration

The SIEF funding has clearly enabled new and enhanced collaboration both among research groups and also with industry. The collaboration with the WCHRI and the Garvan Institute has continued beyond the end of the SIEF funding.

Interestingly, researchers from one of CSIRO’s research collaborators stated that the funding had allowed them to collaborate internally within their organisation. They noted that this would not otherwise have occurred as they worked in separate areas of the organisation.

SIEF funding had also facilitated collaboration with outside bodies. The proposed collaboration with a Swedish research group is one example of this. In addition, the funding facilitated networking which was particularly useful for early career researchers. Some of those early career researchers have subsequently gone on to make joint applications for funding with international research groups at the conclusion of the project.

The SIEF funding has also resulted in discussions with industry about potential products and services that could be commercialised. CSIRO’s longstanding research efforts and engagement with industry in the agriculture sector positions them well to be trusted partners for industry.

C.3.4 Project Outcomes

The outcomes of this project could be important both from a human health point of view and for the health of livestock and the productivity of the farm sector.

The ability to identify epigenetic differences between fat cells in obese and lean adult humans could be used both as a diagnostic and monitoring tool in the prediction and treatment of obesity, as well as to provide new understanding of the functioning these cells and possible points of intervention. If successful, the results could also potentially be used to tailor food industry products to assist with weight loss.

In the case of livestock, a better understanding of the factors influencing brown fat deposition could be important in helping to protect new born lambs. The researchers hope that by increasing the deposition of brown fat it could help protect lambs from hypothermia. If successful, this research could have significant economic benefits as approximately 13 million newly-born lambs die each year.[38] The causes of death include mismothering, starvation and hypothermia. This could deliver economic and environmental benefits as fewer sheep will be needed to produce the same number of lambs.

The research that investigated the links between nutrition during pregnancy and epigenetic markers of infants and their subsequent propensity to suffer from obesity is still in its early stages. It is still unclear whether the results will help to predict the risk that children will become obese later in life.

C.3.5 Adoption

The timeframes of the impacts of the research in terms of commercialisation or changes to medical procedures or practice is likely to vary across different industry sectors. Impacts are likely to be seen more quickly in the livestock sector, possibly in 5 years. They are likely to take much longer to deliver impact in the health and medical sector, possibly 10-15 years.

Some researchers were optimistic about the potential for the predictive genetic and epigenetic tests for humans, given that the application of predictive genetic testing to livestock has been very good. One researcher suggested that, in the future, there is the potential that babies at birth could be given a risk profile based on genetics and epigenetics, which could be updated over their life. This could be an expansion of the current heel prick test given to newborns. However, as noted above, this research still has some way to go before a clear (and strong) case can be made for adoption of a new test.

C.3.6 Impacts

Adult obesity

The Australian Institute of Health and Welfare (AIHW) website reports that almost two thirds of Australian adults (63%) are overweight or obese. A 2008 Access Economics report for Diabetes Australia used obesity prevalence data and obesity attribution factors for a range of illnesses developed by the Australian Institute of Health and Welfare (AIHW). The report found that in 2008 obesity caused:

— 23.8% of type 2 diabetes
— 21.3% of cardiovascular disease
— 24.5% of osteoarthritis
— 20.5% of colorectal, breast, uterine and kidney cancer.[39]

Based on these figures the report estimated that the financial cost of obesity in 2008 was $8.3 billion. Note that this figure did not include the net cost of lost wellbeing, which was valued at almost $50 billion. We have assumed that the availability of this test will help to reduce attribution factors from obesity for the above diseases by 0.1%.

Children

We have assumed that the marginal cost of an obesity diagnostic test that could be administered to all newborns from 2031-32 onwards is $10.00 in 2016-17 dollars. The cost of the test is treated as a lower bound estimate of the value of the test. The public’s willingness to pay for a test that can provide an indication of the risk of future obesity is discussed in Section C.5.2.

Livestock

This element of the research project could have important economic implications for the sheep sector (and potentially other livestock sectors). It could lead to an increase in the reproductive rate of ewes by improving the survival rates of new born lambs. If so, fewer ewes would be needed to produce the same number of surviving lambs which would improve the economics of

38 http://www.hzn.com.au/lambalive.php
39 *The growing cost of obesity in 2008: three years on*, Access Economics for Diabetes Australia, 2008

the sheep sector. Alternatively, the same number of ewes could produce a larger number of surviving lambs.

If we assume that 25% of the approximately 13 million lambs that die every year do so from hypothermia this would imply that some 3.25 million lambs die from this cause each year. Information of the price of lamb on the Meat and Livestock Australia (MLA) website shows that the price of lamb has been roughly between $4 and $5 per kilogram carcase weight (kg cwt).[40] Based on an average weight of a lamb at sale of 50 kg and a standard dressing percentage of 45%, the carcase weight of a lamb would be around 22.5 kg. If we assume a conservative price of $4 per kilo of carcase weight (real 2014 dollars) this implies each lamb lost to hypothermia represents a loss to the producer of around $90. This implies that the value of lambs lost due to hypothermia each year is around $292 million. This is a conservative estimate as it does not take into account the value of the lamb skin (MLA estimates a value of around $10 for a lamb skin).[41, 42]

If we assume that the results of this SIEF funded project enable lamb producers to reduce lamb losses from hypothermia by 10% then the benefit to producers would be around $29 million a year.

The research also points to the potential importance of pre-conception nutrition of livestock (particularly cattle). This in turn leads to the idea of aligning livestock (cow) conception with pasture availability. This may be particularly important in Northern Australia where the harsh climate can compromise the nutrition available from grazing. Cattle in northern Australian are highly vulnerable to not ingesting enough trace elements during grazing. We have not sought to value this potential benefit.

Finally, there could also potentially be environmental benefits if smaller sheep herds were needed to produce the same number of lambs. This benefit would of course not accrue if the same size heard was used to produce larger numbers of (surviving) lambs.

C.4 Clarifying the Impacts

C.4.1 Counterfactual

The project focussing on children would have been hard pressed to obtain funding in the absence of SIEF funding. Collaboration with the researchers on the DOMInO project would not have been possible without SIEF funding. Similarly the collaboration with the Garvan Institute would not have been possible without the SIEF funding. That collaboration has proved vital in supporting the development of new knowledge about epigenetics. One of the research team noted that the collaboration was:

…instrumental in creating a new way of looking at how biology works

It is worth noting that the CSIRO team was primarily focussed on cancer research prior to this project. The SIEF funding was fundamental to allowing the team to develop and use its skills and knowledge to study the risk factors for obesity, and more generally the role played by nutrition. Similarly, the ability of the research team to involve CSIRO researchers with expertise in animal health was crucial to their ability to identify the potential benefits of the research to the livestock industry.

While some research would have been done the level of detail of those investigations would be much reduced without the SIEF funding. We have assumed that in the absence of SIEF funding the research outcomes would have been delayed by 10 years.

C.4.2 Attribution

We have assumed the following attributions for the impacts flowing from this project:

40 Australian Sheep Prices, http://www.mla.com.au/prices-markets/Trends-analysis/real-price-reports/ accessed October 2016.
41 *Comparing lamb marketing methods*, NSW Agriculture.
42 *NLRS (National Livestock Reporting Service) Sheep Assessing*, www.mla.com.au/files/.../assessing-sheep-and-lambs-livestock-descriptions[1].pdf accessed October 2016.

- Adult obesity research – 70% to SIEF and 30% to the Garvan Institute
- Childhood obesity research – 50% to SIEF, 50% to University of South Australia
- Livestock related research – 70% to SIEF, 30% to the firm who assisted in the process of commercialising the technology.

C.5 Evaluating the Impacts

C.5.1 Cost-Benefit Analysis

Costs

As noted previously, SIEF funding for the project was: $1.208 million (2011-12), $1.806 million (2012-13), $1.724 million (2013-14), $0.606 million (2014-15) and $0.881 million (2015-16).

Benefits

Reduction in future cost of obesity

According to the PwC study referred to previously[43], the cost of obesity in Australia was $8.3 billion in 2014-15, excluding personal well-being costs. It is assumed that the cost of obesity rises by 3% per year in real terms, and that the SIEF-funded research is able to reduce the annual cost of obesity by 0.1% from 2028-29 onwards. As discussed previously, it is assumed that 70% of the resultant benefits is attributable to SIEF.

Diagnostic test for newborns

As discussed above, due to the uncertainties around this project, we have not included any benefits associated with a possible future diagnostic test for newborns. However, should such a test become available then the benefits could be considerable.

Reduction in lamb mortality

It is assumed that the number of lamb deaths remains constant at 13 million a year, and that 25% of such deaths are due to hypothermia. The price of lamb per kg carcase weight is assumed to be constant at $4.00 in 2016-17 dollars, while the average carcase weight per lamb is assumed to be 22.5 kg.

It is assumed that the SIEF-funded research will enable a 10% reduction in lamb deaths from 2021-22 onwards, and that 70% of the benefits from reduced lamb mortality is attributable to SIEF.

Assessment of benefits against costs

The present value of SIEF funding is $6.23 million in 2016-17 dollars based on a 7% real discount rate. ACIL Allen has calculated the present value of all project benefits as $428.2 million in 2016-17 dollars under the same discount rate.

The net present value (NPV) of the project is therefore $422 million in 2016-17 dollars under a 7% real discount rate. The benefit-cost ratio (BCR) of the project is 69.1.

Sensitivity analysis

The BCR of the project:

- Increases to 70.1 if the costs of obesity in Australia rise by 5% a year instead of 3% a year.
- Increases to 81.7 if the SIEF-funded research reduces the annual cost of obesity by 0.5% instead of 0.1%.
- Decreases to 58.1 if the SIEF-funded research reduces the incidence of lamb mortality due to hypothermia by 5% instead of 10%.

[43] PwC, *Weighing the cost of obesity: A case for action*, October 2015.

C.5.2 Potential future impacts

Preliminary research (undertaken with support from the NSW Office of Health & Medical Research Innovation program) suggested that Australians would be willing to pay up to $250 to obtain a predictive test for obesity and other health issues for children.

Should the SIEF funded research eventually lead to a new diagnostic test for new born children around the world then the value generated could be considerable.

The research on sheep epigenetics has also highlighted the potential to accelerate the genetic selection of breeding animals. In the past, the process of genetic improvement had a cycle time of about six years. Recent advances in genetics have already decreased the required cycle time to about three years. However, the research done under this project could lead to a test being developed in five to ten years' time, which could reduce the required time to a few months or less. This particular outcome was not one that was initially expected to arise from the project. However, the impacts have the potential to be profound for the industry.

There is also the potential to extend the technology developed for decreasing lamb mortality to other livestock.

C.5.3 SIEF's role as an Innovation Catalyst

The research done during the SIEF funded EpiScope project has enabled potential innovation in a number of ways. For example:

— The ability to connect the results from the human obesity research to CSIRO's existing work in the field of diet to potentially market new products or services to persons battling obesity.

— The research on sheep epigenetics which has the potential to very significantly accelerate the genetic selection of breeding animals. This was an unexpected consequence of the research.

— The partnership with an agricultural firm to trial the application of the research outputs for decreasing lamb mortality is a sign of the level of trust between industry and CSIRO that helps to catalyse innovation.

C.5.4 Distribution effects on users

The main potential beneficiaries from the SIEF supported research into early nutrition are persons who either are obese or at risk of becoming obese, livestock breeders and businesses that are able to market new products or services.

CASE STUDY: ENERGY WASTE (METAL-ORGANIC FRAMEWORKS)

D

BOX D.1 ENERGY WASTE - EXECUTIVE SUMMARY

Key findings

The outputs of the Energy Waste project has led to a number of possible applications, namely:

- An anti-corrosive coating. Initially this is being developed for use on aircraft, but the marine and automotive markets are other longer term options.
- New more durable air filters for use by defence personnel and civilian first responders.
- A delivery mechanism for the controlled release of enzymes.
- A more efficient use of resources for producing plastic pipes.

Innovation impact

The researchers in this project drew on the skills and experience of other parts of CSIRO to develop a pilot plant that is able to reliably produce large quantities of many different MOFs. They also identified several potential commercialisation pathways for new and innovative products and were able identify partners to begin to explore these.

This case study uses the evaluation framework outlined in the CSIRO Impact Evaluation Guide. The results of applying that framework to the Energy Waste case study are summarised in **Figure D.1**.

D.1 Purpose and audience for case study

This case study describes the economic, environmental and social benefits arising from the Science and Industry Endowment Fund (SIEF) Research Project '*Solving the Energy Waste Roadblock*' (RP02-035).

The information in this case study is provided for accountability, communication and continual improvement purposes. Audiences for this report may include Members of Parliament, Government Departments, SIEF, CSIRO, other researchers and the general public.

FIGURE D.1 SIEF CASE STUDY ENERGY WASTE – IMPACT FRAMEWORK DIAGRAM

INPUTS	ACTIVITIES	OUTPUTS	OUTCOMES	IMPACTS
– SIEF investment of $6 million – In-kind support of around $8 million from seven research partners	– Research – Testing – Construction of a MOF pilot plant	– Results of research – A pilot scale MOF manufacturing plant – 87 Publications – 2 Awards – Fourteen patents	– Partnerships with five organisations to investigate five possible commercialisation opportunities – Possible licencing fees	– Improved sustainability of businesses – Fewer deaths or injuries among defence personnel and first responders – Increased exports – Employment growth – Contribution to GDP?

SOURCE: ACIL ALLEN

D.2 Background

The ongoing burning of coal and gas for electricity generation is a major contributor to the steady increase in global carbon dioxide (CO_2) emissions and the rising concentration of that gas in our atmosphere. The effects of increasing the amount of CO_2 in our atmospheric are well established. However, technologies for reducing our dependence on fossil fuels have not been developed and deployed rapidly enough to reverse the steady increase in CO_2 emissions and the world faces the prospects of very significant changes to our climate and oceans. It is essential that economically viable technologies for capturing, storing and using CO_2 be researched and developed.

The Energy Waste project, which ran from 1 December 2011 to 1 September 2016, sought to find answers to some of the key challenges for reducing greenhouse gas emissions on a national and international scale, namely, the development of new materials and processes for the capture and utilisation of CO_2. The multidisciplinary research team assembled for the project carried out research in four key areas, namely:

- The synthesis of novel Metal-Organic Framework materials (MOFs) with exceptional CO_2 separation capacities.
- The development of MOFs with catalytic abilities for CO_2 conversion into usable products.
- The scale-up and fabrication of membrane-based devices for integration of MOFs into industrial platforms.
- The modelling, prediction and advanced characterisation of the new materials.

Through this suite of research topics the project sought to address two distinct challenges, namely to:

- Develop new materials that can be used to separate CO_2 efficiently and cost-effectively from the exhaust gas of a coal or gas burning power station. Current carbon capture technologies are energy intensive and costly and this creates a major economic barrier to their commercial application.
- Develop technologies that can convert captured CO_2 into useful products. For example, an energy carrier (such as methane or ethanol) or a chemical feedstock (e.g. acetic acid). Currently most captured CO_2 is regarded as a waste product to be disposed of by injecting it underground.

However, if it proves possible to develop catalytic chemistry to convert waste CO_2 into a product with economic value then this would help improve the economic viability of carbon capture.[44]

A third element of the project was to scale up the production of the MOFs developed by the research team. The intended end users of the research outputs from this project are the oil and gas, chemical manufacturing, and power generation industries. The ultimate objectives of this research project are to:

— Make a significant contribution towards the fundamental understanding of the capture, diffusion and catalysis of carbon dioxide within metal-organic frameworks (MOFs) and related materials.

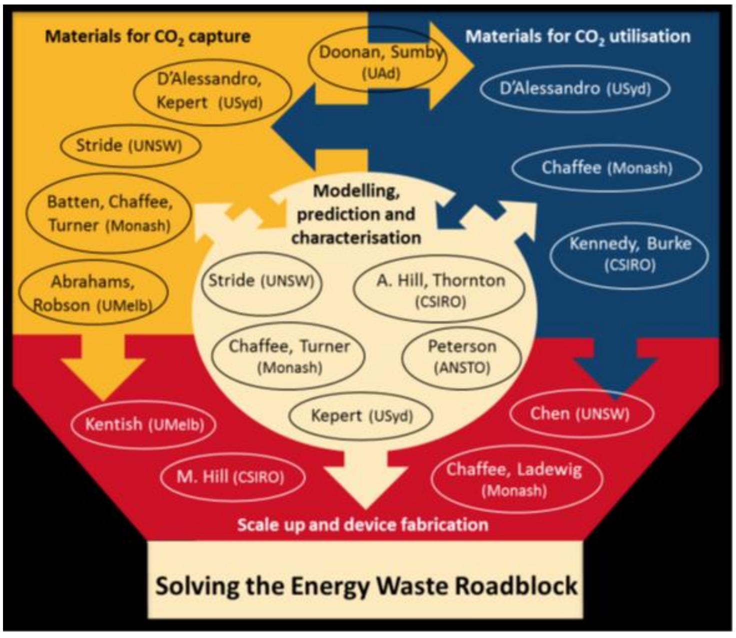
— Develop materials and systems ready for commercialisation, in partnership with the intended end users.

The project focused on a particular 'family' of materials known as "metal-organic frameworks" or MOFs. Research into MOFs first began about two decades ago. Since then MOFs have emerged as a highly promising source of functional materials with a very wide range of applications. MOFs are composed of metal atoms bridged by organic molecules in a highly porous network or scaffold. Having a known, regular and modular structure at a molecular level gives chemists an unprecedented opportunity to understand the properties of these materials and seek to tailor them for specific purposes.

The project assembled a highly multidisciplinary team of 19 lead researchers from seven institutions. The team brought together synthetic chemists who were experienced in materials design and preparation, theoretical chemists able to model and predict gas interactions at the molecular scale, and chemical engineers who are fabricating membranes and designing scale-up strategies for pilot plants. This depth of expertise was augmented by a dozen early-career researchers and over 20 postgraduate research students. The researchers also partnered with major national facilities at Australian Nuclear Science and Technology Organisation (ANSTO) and the Australian Synchrotron to help them measure and characterise the structure and properties of the materials they were developing and studying.

The contributors to the research, their roles and the relationships between their various research activities are shown in **Figure D.2**.

FIGURE D.2 VISUALISATION OF RESEARCHER ROLES AND RELATIONSHIPS



SOURCE: CSIRO

44 Virtually all the CO_2 capture plants in operation today use the captured CO_2 for enhanced oil recovery (EOR).

D.3 Impact Pathway

D.3.1 Project Inputs

The total cost for the Energy Waste project was some $14.0 million in cash and in-kind contributions. SIEF contributed $6.0 million (or around 43% of the total cost), the University of Sydney, CSIRO, the University of New South Wales, ANSTO, and the University of Melbourne contributed $8.0 million (or 57% of the total). **Table D.1** shows the cash and in-kind support provided over time to the Energy Waste project.

TABLE D.1 CASH AND IN-KIND SUPPORT – ENERGY WASTE PROJECT ($MILLION)

Contributor / type of support	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	Total
Cash							
SIEF	$741,046	$1,425,032	$1,495,332	$1,395,757	$342,833	$600,000	$6,000,000
In-kind							
CSIRO	$95,775	$223,342	$235,643	$200,655	$141,091	$21,776	$918,282
University of Sydney	$114,973	$243,032	$251,529	$264,105	$194,334	$29,994	$1,097,967
University of NSW	$77,802	$158,448	$162,695	$170,830	$125,700	$19,401	$714,876
University of Adelaide	$95,744	$183,670	$184,804	$192,544	$140,698	$21,678	$819,168
ANSTO	$214,099	$381,749	$378,878	$396,593	$290,986	$44,878	$1,707,183
University of Melbourne	$80,644	$295,239	$332,393	$349,012	$256,810	$39,653	$1,353,733
Monash University	$155,604	$316,896	$325,391	$341,660	$251,400	$38,800	$1,429,751
Grand Total	**$14,040,960**						

SOURCE: CSIRO

D.3.2 Project activities

The project team identified four key challenges as needing to be overcome if the capture and use of CO_2 on an industrial scale with MOF-based devices was to be possible. Each of these challenges was addressed under one of the four following sub-projects:

Materials for CO_2 capture

With a few notable exceptions, most known MOFs do not perform well under industrially relevant conditions since they are only moderately stable under the chemical and thermal conditions of most relevant industrial processes. Drawing on their combined expertise in design, synthesis and characterisation, the research team targeted the development of MOF materials for optimal CO_2 separation under the high temperature and humidity conditions present in flue streams from industrial power stations.

The research team identified mixed-matrix membranes as the most promising approach. In this approach nano-sized particles of the MOF are incorporated into very thin polymer membranes. The research began with proof-of concept flat membranes at the laboratory scale. These were thoroughly characterised for their separation properties and resistance to the various toxic and corrosive gases found in flue gas. The research team then moved on to investigate more complex membranes suited to industrial-scale separations, such as hollow-fibre membranes and spiral wound membranes.

Materials for CO2 utilisation (catalysis)

Carbon dioxide is not only a powerful greenhouse gas, but a potential feedstock for many commercial chemicals. Over recent decades there has been considerable research on the conversion of CO_2, however the possibility of using MOF materials as a catalyst for this purpose had been almost entirely unexplored. The research team used the results of past research on

CO_2 conversion to design and evaluate MOF materials with the ability to convert CO_2 into usable products.

For the first time they were able to establish a materials design approach that incorporated known catalytic complexes into open-framework MOF-type materials. Distinct families of catalytic materials were designed and tested for photocatalytic, electrocatalytic and more conventional gas-phase systems. Each of these represented an advance in the field. One of the challenges of the research was that the structural complexity required to incorporate active sites reduced the stability of the MOF. The team is continuing to work to address this challenge.

Scale-up and device fabrication

The integration of MOFs into practical CO_2 capture processes required substantial work to scale-up the production of MOFs and the fabrication of membrane-based devices.[45] The most promising gas separation technology in which to use MOFs was identified to be mixed-matrix membranes, in which nano-sized particles of the active material are incorporated into very thin polymer membranes.

The team started with proof-of-concept flat membranes at the laboratory scale and was able to thoroughly characterise their separation properties and resistance to the various toxic and corrosive gases found in flue gas. The research then continued on to investigate more complex membranes suited to industrial-scale separations including hollow-fibre membranes and spiral wound membranes. Testing protocols to assess materials for their CO_2 separation and conversion efficiencies were also developed.

Modelling, prediction and characterisation

Key to the development of MOF technologies was a fundamental understanding of their molecular structure and the way in which they interact with the CO_2 molecule. This understanding was achieved by combining the high resolution structural information obtained through X-ray and neutron diffraction with the results of high level computational simulations.

D.3.3 Project outputs

The research carried out under the Energy Waste project has delivered some important outputs.

This includes a very substantial library of candidate materials for separating gases. In particular, the researchers developed a number of successful strategies for the design and synthesis of porous MOFs for CO_2 separation, and these strategies have been refined and extended to optimise materials performance. Particular advances were made in understanding the interactions and behaviour of carbon dioxide molecules within the pores of MOF materials, using both advanced structural studies and computational modelling.

As part of this work on gas separation technology the research team identified mixed matrix membranes as the most promising gas separation approach. This technology involves incorporating nano-sized particles of the MOF into very thin polymer membranes. The research team has developed world-leading expertise in incorporating MOFs into separation membranes. It was the first in the world to report an effective means to totally inhibit polymer aging without any loss of gas permeability or membrane selectivity. This research has led to two provisional patents.

The team also reported a MOF material which, after adsorbing CO_2, will release it when irradiated by light. This work was published Angewandte Chemie and classed as a "Very Important Paper" (top 5%).

However, the current policy settings for reducing greenhouse gas emissions mean that the CO_2 capture process using MOFs is not economically viable.

In March 2014 the Australian partners in this research project announce a collaboration with the M^4CO_2 consortium, a four year research project funded under the European Union's 7th

45 For example, several thousand tonnes of MOFs would be required if they were to be used to capture CO_2 from a power station.

Framework Program. This will allow linkages to be established between Australian and European research groups developing MOF-based mixed-matrix membranes for CO_2 separation.

More recently discussions with Indian partners have proven successful, and the CSIRO team are now in a development project with the Government owned oil and gas firm, Hindustan Petroleum Corporation Limited (HPCL).

The research team also developed a mechanism that allows them to incorporate known catalytic complexes into open-framework MOF-type materials. Several distinct families of catalytic materials were designed and tested for photocatalytic, electrocatalytic and more conventional gas-phase systems. This leading edge research was reported in a 'milestone' paper that attracted global attention.

The researchers also found that when the pores in certain MOFs are loaded with catalytically active metal salts and heated, they decompose to form very active nano-structured catalytic materials, which perform considerably better in gas phase reduction of CO_2 than current commercial catalysts.

A Ruthenium MOF was identified as the most promising, however, the high cost of this metal makes its use commercially unattractive. In addition, the structural complexity required to incorporate active sites led to reduced stability. However, work is continuing in this area.

Perhaps more importantly, the research team also developed a pilot scale MOF manufacturing plant that has been tested and shown to be able to produce some 35 different MOFs using a continuous flow process. The researchers drew on the experience of the CSIRO's Minerals Group to develop the plant. This is an excellent example of the cross fertilisation of ideas and skills that CSIRO is able to deliver as part of its research effort. The conventional way of making MOFs is based on a batch process and scaling this up has been a persistent challenge to scientists for many years. The continuous flow approach to manufacturing MOFs has managed to reduce the time taken to reliably make consistent quality MOFs from several days to a few minutes. CSIRO is now a world-leader in this field, having developed a flow reactor capable of producing many kilograms of MOFs per hour.

A spin-off company (MOFWORX) has been created to market the capability developed. The aim is to use the technology to manufacture MOFs that have been designed to meet specific needs so that they can be incorporated into commercial products, rather than market the actual manufacturing technology (see discussion in Section D.3.4).

Awards

The researchers working on this project have received the following awards:

— In July 2015 Dr Ravi Babarao was awarded a ProsPer.net Scopus Young Scientist Award. This award is given annually to a young scientist or researcher, based in the Asia-Pacific region, who has made a significant contribution in the area of Sustainable Development. Ravi, who won the Energy category, receives a prestigious Alexander von Humboldt fellowship to conduct research in Germany.

— In October 2015, one of the leaders of this research project, Dr Matthew Hill, was announced as the winner of the 2014 Malcolm McIntosh Prize for Physical Scientist of the Year, one of the annual Prime Minister's Prizes for Science.

Publications and patents

The research carried out under this SIEF supported project has led to substantial contributions to our understanding of the fundamental science of MOFs and related materials. The research has resulted in some 87 refereed publications, many in leading journals.

There have also been three families of patents granted (a total of 14 patents in all) that cover the research carried out under this project. There is also at least one other patent application currently being prepared.

D.3.4 Project Outcomes

The outputs from this project have significantly improved our understanding of the fundamental science around MOFs. The project's Industry Advisory Board and the research team's existing relationships with commercial partners has also helped direct research outputs towards a number of possible commercial applications (outcomes).

As mentioned above, the applications initially specified as the likely objectives for this project (i.e. carbon capture) are still viewed as some way off based on current policy settings. However, there are currently five other potential commercialisation opportunities actively being pursued, namely:

1. *An anti-corrosive coating* (Technical Readiness Level (TRL) 7) - Current anticorrosive coatings tend to be based on chromates. There are a number of negative health implications associated with chromates (particularly hexavalent chromium).[46] The new MOF based approach to anticorrosive coatings does not use chromates and would avoid these risks. The product is being developed in partnership with a multinational aeronautical company.[47] Under the terms of the agreement CSIRO is entitled to develop anticorrosive coatings in other areas should it wish to.
2. *Toxic gas filter* (TRL 4) – While the MOFs currently are designed to capture CO_2, the size and chemistry of the pores in the MOFs can be varied to target the capture of differing chemicals. On 2 November 2016 the Minster for Defence Industry, the Hon Christopher Pyne, MP, announced the signing of a $3.2 million innovation collaboration agreement between Defence and the CSIRO. The collaboration will lead to a production-ready prototype of a new broad spectrum chemical, biological and radiological respirator filter for the Australian Defence Force (ADF).

   In announcing the collaboration Minister Pyne said:

   This is a wonderful example of leveraging world class Australian scientific research and development to produce a respirator canister that provides levels of protection unavailable today.[48]

   The CSIRO has been working with Defence since February 2016 to develop a prototype filter that could meet the ADF's capability needs for respiratory protection. Following successful completion of the proof of concept phase of the project, Defence provided funding of $3.2 million to enable CSIRO to incorporate MOFs into a filter canister for use with the in-service respirator. This work is initially aimed at the 40,000 front line soldiers of the defence force. In due course the technology could be extended to first responders and other allies.

1. *Breathing apparatus* (TRL 5) – MOFs can ensure that a breathing apparatus can remain effective for a longer period of time, and in a safer fashion. This will be a civilian application of the respirator filters initially developed for the defence force.
2. *Controlled release of enzymes* TRL 4 – By encasing the enzymes in a purpose designed MOF they can be stabilised when exposed to heat. The MOF coating is porous so it is possible to have a steady release of enzymes over time. This technology is being developed for a non-medical application (in order to get a faster route to impact). The application is global. The work is being done in partnership with a large multinational firm.
3. *Enhanced plastic piping* (TRL 3) – The technology is expected to enable the production of a premium plastic product that would enable both the production of thinner pipes (i.e. requiring less material for the same strength) or larger pipes (without weight problems) The development is being done in partnership with an Australian chemical company.

The ability of CSIRO to quickly move to investigate a range of alternative paths to market for the technologies developed as a result of this project is an excellent demonstration of the organisations understanding of the importance of identifying the potential commercial applications of the technology. The fact that CSIRO was able to identify five different partners to investigate these possible paths to market speaks volumes about the level of trust that CSIRO has developed among the Australian business community.

[46] An investigation into hexavalent chromium release into drinking water was the basis of the true story of Erin Brockovich, dramatized in the film of the same name.
[47] Primer paint containing hexavalent chromium is used for aerospace refinishing applications.
[48] https://www.pyneonline.com.au/media-centre/media-releases/defence-and-csiro-to-produce-prototype-respirator-filter-to-protect-soldiers

D.3.5 Adoption

The researchers anticipate that if the development work on the above projects goes well then the first commercial products could begin to emerge in 18 months to five years, depending upon the technical readiness level of the technology. Based on this information, ACIL Allen has assumed that products for each of the areas mentioned above could become available as follows:

1. Anti-corrosive coatings in around 18 months
2. *Toxic gas filters* in around four years
3. *Breathing apparatus* in around three years
4. Controlled release of enzymes in around four years
5. Enhanced plastic piping in around five years.

We have assumed that there will be a gradual uptake of any products that ultimately become available. The rate of uptake will vary between the various projects. This is discussed in more detail below.

D.3.6 Impacts

Anti-corrosive coatings

A March 2015 report by a market research firm projected that the anti-corrosion coating market would be US$26.5 billion by 2019. The report projects that the market will have a compound annual growth rate (CAGR) of 4.5% between 2014 and 2019.

The report identified the Asia-Pacific region as leading the growth in the anti-corrosion coating market. It noted that several anti-corrosion companies are expanding in Asian countries to benefit from the low-cost structures and growing local demand for anti-corrosion coatings for various applications, including marine, oil and gas, power generation, infrastructure, industrial (repair and maintenance) and automotive and transportation.[49]

A 2002 study on the cost of corrosion in the US found that the annual estimated cost of corrosion was US$276 billion (or about 3.1% of US GDP).[50] The study found that the cost of aircraft corrosion was $2.2 billion or just below 0.8% of the total cost of corrosion.

If we assume that a similar relationship between the cost of corrosion and GDP applies in Australia then, based on Australia's GDP of $1.6 trillion in 2015 the total cost of corrosion could have been around $50 billion in that year. Again, based on the share of that cost that is due to aircraft corrosion in the US, the annual cost of aircraft corrosion in Australia could potentially be around $390 million.

The US study estimated that between 25 and 30% of the cost of corrosion could be saved if optimum corrosion management practices were used. This suggests that around $100 million of the cost of aircraft corrosion could potentially be avoided. If we assume that aircraft operators would be prepared to spend say 50% of that amount to reduce corrosion then that suggests that the Australian market for aircraft corrosion protection might be around $50 million a year.

The potential economic benefit from this work will at least initially be from royalties flowing to CSIRO from the commercialisation agreement between MOFWORX and the commercial partner for the work. We have assumed that the royalty rate will be 5%.[51] If the CSIRO technology captures half the estimated market then this would suggest a royalty stream of around $1.25 million a year.

The research team is presently in negotiations with potential users of the anti-corrosion technology outside of the aeronautical space sector. We have not sought to assign any value resulting from the commercialisation of the technology in other sectors, although we note that markets in the automotive and marine sectors is significantly higher than the aeronautical sector.

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49 http://www.prnewswire.com/news-releases/anti-corrosion-coating-market-is-projected-to-grow-at-45-cagr-to-2019-globally-294851421.html accessed 19 September 2016.

50 *Corrosions Costs and Preventative Strategies in the United States*, CC Technology Laboratories Inc., 2002.

51 This is the middle of the normal range of royalty rates for CSIRO of between 3 and 8 per cent.

Toxic gas filters

A search of the internet suggests that CBRN filter cartridges cost around US$50 (or around A$65) each for a military grade gas mask.[52] [53] If the collaboration between Defence and CSIRO to develop a filter cartridge that incorporates the MOF technology proves successful then, assuming that each mask would need two cartridges (one fitted and one spare), the potential initial market for cartridges would be worth around $5 million over an assumed four year adoption period. If after that initial four year period, some 10% of the cartridges were replaced each year then this could generate sales of around $500,000 a year and a potential royalty income stream of $25,000 a year (based on a 5% royalty rate).

Breathing apparatus

This possible application could be the second product commercialised as a result of the research done on this project. ACIL Allen has assumed that this application could be used by Australian fire fighters. There are currently around 13,000 professional fire fighters in Australia.[54]

The aim is to develop a single use breathing apparatus for use by fire fighters. If we assume that there are two breathing apparatuses for each firefighter this would be a total of 26,000 apparatuses that could potentially be supplied using the new technology. If 25% were replaced each year then the market would be for a total of 6,500 apparatuses each year. ACIL Allen estimates that the price of a breathing apparatus for use by first responders would be around $200. This would imply that sales revenue might amount to some $1.3 million a year. If CSIRO received a royalty equivalent to 5% of sales revenue then this would amount to $65,000 a year.

The benefits could of course be orders of magnitude higher if the breathing apparatus incorporating the CSIRO technology captured a share of the global market for such equipment.

Controlled release of enzymes

There are a number of possible applications for this technology. For example, it could potentially be used in the fields as disparate as vaccine delivery to remote regions to improving the performance of laundry powder. While it is too early to be able to judge the precise benefits of the application of the technology in this way, the scale of the global markets for these products is huge and the potential benefits could be considerable.

Enhanced plastic pipes

The benefits from the application of this technology could be considerable. While the details of the collaboration with industry are confidential, the figures for manufacturing of PVC pipe illustrate the potential scale of the benefits. ACIL Allen understands that there are approximately 100 kilotons of PVC piping sold annually in Australia. The PVC resin used to manufacture the pipes sells for around $2.50 a kilo.[55] Hence the total cost of the material used to manufacture PVC pipe is some $250 million a year. If CSIRO's technology enabled the industry to use 5% less resin to manufacture their PVC pipes this would represent a saving of $12.5 million a year to the manufacturer.

As noted above, the nature of the collaboration is confidential, however the CSIRO have estimated that the royalties from the commercialisation of the technology would be around $300,000 in the initial years.

52 CBRN filters are filters that protect against refers to chemical, biological, radiological and nuclear dangers.

53 See for example, http://www.approvedgasmasks.com/filter-3mCBRN.htm, accessed November 2016.

54 "*History of the United Firefighters Union of Australia*". http://www.ufua.asn.au/about/history-of-the-united-firefighters-union-of-australia/ accessed 4 October 2016.

55 Personal communication from a member of the Society of Plastics Engineers, October 2016.

D.4 Clarifying the Impacts

D.4.1 Counterfactual

SIEF funding was reported as being instrumental in getting this research project off the ground. The researchers argued without the SIEF funding it would not have been possible to form the collaborative teams necessary to carry out this research.

While there are other groups working on MOFs the SIEF funded work has led to some excellent outputs. Interestingly, most of these are outside the area that the research project was initially focussed on.

The development of a scalable process for producing significant amounts of MOFs 'to order' is a major breakthrough that could prove to be a very important enabler for the more widespread use of MOFs in wide range of different industries. The portfolio of collaborative projects with potential end users is a clear sign of the potential value that the private sector attaches to this capability.

While it is possible that others will be able to duplicate the technology for manufacturing MOFs, the importance of being the first mover should not be underestimated.

D.4.2 Attribution

The partners in the research project see the attribution of benefits from this project resting entirely with SIEF. They argue that without SIEF it would not have been possible to form the collaborations and meet the costs of bringing the postgraduate and postdoctoral students into the research team.

D.5 Evaluating the Impacts

D.5.1 Cost-Benefit Analysis

Costs

SIEF funding for the project was: $0.741 million (2011-12), $1.425 million (2012-13), $1.397 million (2013-14), $1.444 million (2014-15), $0.393 million (2015-16) and $0.600 million (2016-17).

Benefits

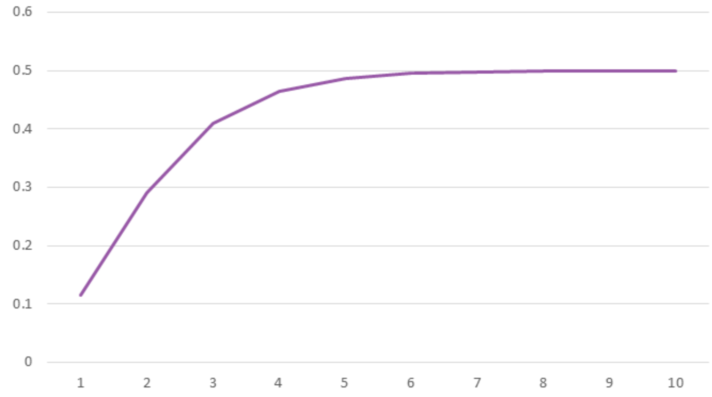
Anti-corrosive coatings

As discussed above, the cost of corrosion in the US was US$276 in 2002, of which US$2.2 billion was the cost of aircraft corrosion. The size of the US anti-corrosion coating market in 2019 has been estimated at US$26.5 billion. Assuming that the size of the anti-corrosion coating market is proportional to the cost of corrosion, ACIL Allen estimates that the size of the US aircraft anti-corrosion market in 2019 will be approximately US$211 million.

Scaling the size of the US aircraft anti-corrosion market by the relative size of the US and Australian economies (which were US$17.91 trillion and A$1.62 trillion in 2015 respectively), ACIL Allen estimates that the size of the Australian aircraft anti-corrosion market in 2019 will be approximately A$19.10 million (or $18.18 million in 2016/17 dollars, assuming a 2.5% inflation rate).

We have assumed that the Australian aircraft anti-corrosion market grows by 4% a year, and that the anti-corrosion product developed as a result of the SIEF-funded research achieves a market share of 50% over a 6-year period (see the Gompertz market penetration curve below).

FIGURE D.3 MARKET PENETRATION (% MARKET PENETRATION OVER TIME (YEARS))



SOURCE: ACIL ALLEN

We have assumed that 20% of the value of the anti-corrosion product derived from the SIEF-funded research "leaks" out of the Australian economy through inputs that have to be sourced from overseas.

Toxic gas filters

It is assumed that the value of the market for filter cartridges increases by $0.25 million a year between 2019-20 and 2023-24, from $0.50 million to $1.50 million (for new filters fitted to in-service respirators), and then remains at $0.50 million thereafter (for replacement filters).

It is assumed that 20% of the value of filter cartridges derived from the SIEF-funded research "leaks" out of the Australian economy through inputs that have to be sourced from overseas.

Breathing apparatus

It is assumed that the firefighter workforce, currently 13,000 strong, grows by 2% a year. It is assumed that each firefighter requires 2 breathing apparatus, of which 25% are replaced each year. The price of each breathing apparatus is assumed to be $200 in 2016-17 dollars.

It is assumed that production of the breathing apparatus which incorporates the technology developed from the SIEF-funded research commences in 2019-20.

Enhanced plastic piping

It is assumed that CSIRO will receive $300,000 in royalties in 2019-20 for the technology generated from the SIEF-funded research, and that royalties constitute approximately 5% of the reduction in production costs that is enabled by the new technology. Royalties to CSIRO are assumed to grow by 5% each year from 2019-20 onwards.

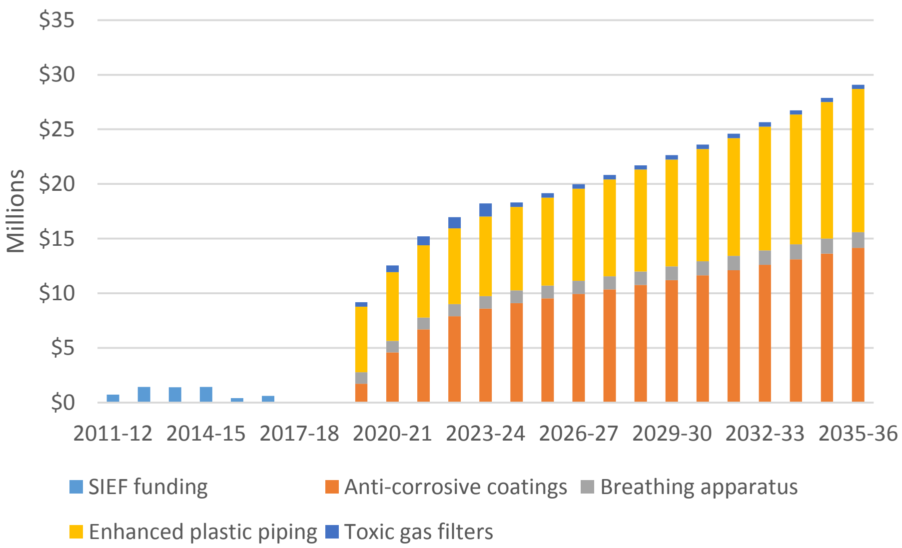
Assessment of benefits against costs

The costs and benefits of the project to 2035-36 are shown in **Figure D.4.**

The present value of SIEF funding is $7.29 million in 2016-17 dollars under a 7% real discount rate. The present value of all project benefits is $151.6 million in 2016-17 dollars under the same discount rate.

The net present value (NPV) of the project is therefore $144.3 million in 2016-17 dollars under a 7% real discount rate. The benefit-cost ratio (BCR) of the project is 20.79.

FIGURE D.4 PROJECT COSTS AND BENEFITS BY YEAR TO 2035-36 ($M, 2016/17 DOLLARS)



SOURCE: ACIL ALLEN

Sensitivity analysis

The BCR of the project:

- Decreases to 19.26 if the Australian aircraft anti-corrosion market grows by 2% a year instead of 4% a year.
- Increases to 22.09 if the proportion of breathing apparatus for firefighters that needs to be replaced each year is 50% instead of 25%.
- Increases to 25.01 if the royalties for the technology that reduces the production cost of plastic piping grows at 10% a year instead of 5% a year.
- Decreases to 16.18 if royalties as a proportion of the reduction in production costs of plastic piping is 10% instead of 5%.

D.5.2 Potential future impacts

Several of the technologies that the researchers are seeking to commercialise in partnership with various firms could generate significant additional benefits in the longer term.

For example, the anti-corrosion product could be applied in the marine or automotive sector. These are both much larger markets than the aviation sector. This would have economic benefits, environmental benefits (as a result of reduced use of chromates) and health benefits from reducing the risk of workers being exposed to chromates.

Similarly, the filters for defence and civilian purposes and the pipe making technology could potentially capture large international markets.

The use of the technology developed under this project for the reliable delivery of enzymes over time could, if successful, deliver significant economic and health benefits.

D.5.3 SIEF's role as an Innovation Catalyst

The ability of the researchers in this project to draw on the skills and experience of their organisation (in this case other parts of CSIRO) to develop a pilot plant that is able to reliably produce large quantities of many different MOFs and then identify several different potential commercialisation pathways for new and innovative products when the original objective of the project proved to be impractical illustrates SIEF's role as an innovation catalyst.

D.5.4 Distribution effects on users

The main beneficiaries of this project will be the businesses that are able to market new products or services to consumers.

D.5.5 Externalities or other flow-on effects on non-users

There will be potential health and safety benefits for the users of the technology, such as the defence or first responder personnel that make use of the improved filters. There are also possible benefits to the environment and health of workers from being able to reduce the use of chromates as an anticorrosion treatment.

E CASE STUDY: RAFT FOR BIOMEDICAL APPLICATIONS

BOX E.1 RAFT FOR BIOMEDICAL APPLICATIONS - EXECUTIVE SUMMARY

Key findings

The research into the medical uses of RAFT technology has led to:

— The development of a polymeric scaffold for targeted drug delivery, through conjugation of both a cytotoxic small molecule drug and an antibody fragment.
— The possible use of RAFT polymers for the development of more rapid and accurate tests for cancer.

Innovation impact

The research team's work on using RAFT technology as a mechanism for the delivery of therapeutic agents is world leading and at the forefront of this relatively new field of research.

This case study uses the evaluation framework outlined in the CSIRO Impact Evaluation Guide. The results of applying that framework to the RAFT[56] for Biomedical Applications case study are summarised in **Figure E.1**.

E.1 Purpose and audience for case study

This case study describes the economic, environmental and social benefits arising from SIEF's funding for the RAFT for Biomedical Applications project (the RAFT project) (SIEF identifier RP02-051).

This information is provided for accountability, communication and continual improvement purposes. Audiences for this report may include Members of Parliament, Government Departments, SIEF, CSIRO, other researchers and the general public.

E.2 Background

There is strong interest in the development of new ways of delivering therapeutics and imaging agents, new responsive implantable biomaterials and scaffolds for regenerative medicine, wound care applications, and clinical diagnostic and laboratory devices. To address these needs, new polymer materials are being developed. To date, these materials have been predominantly

[56] RAFT is Reversible Addition Fragmentation chain Transfer

designed to have properties such as elasticity, durability, degradability and to be biologically inert or "inactive".

FIGURE E.1 RAFT CASE STUDY – IMPACT FRAMEWORK DIAGRAM

INPUTS	ACTIVITIES	OUTPUTS	OUTCOMES	IMPACTS
– SIEF investment – Investment by Cochlear Ltd – In-kind support from CSIRO, the University of Washington, Cochlear Ltd and the O'Brien Institute	– Collaborator research at the University of Washington and Cochlear Ltd – Testing of bioactives	– New Australian IP based on CSIRO's RAFT technology – Publications – To date, one provisional patent – Knowhow for a US-based spinout company	– Possible new treatment for brain cancer – Possible new cancer treatments using Antibody Conjugates (ADCs) – Possible future licencing fees from ADCs – New Immuno-histochemistry test (Planet Innovation)	– Possible better social outcomes for cancer patients – Possible reduced deaths from cancer – Increased international trade – Possible additional research funding for CSIRO to continue RAFT work – Contribution to Australian GDP

SOURCE: ACIL ALLEN

The SIEF RAFT for Biomedical Applications project aimed to use the versatility of the Reversible Addition Fragmentation chain Transfer (RAFT) process to help deliver the next generation of polymer based materials for the Australian biomedical industry. RAFT addresses the key challenge of developing next generation of polymeric materials to provide "active" materials capable of promoting desired biological responses (e.g. targeted delivery, interaction with specific cell and tissue types or programmed cell responses).

To help deliver the next generation of "active" polymer based materials, CSIRO's RAFT technology has been exploited to gain access to polymers with highly defined size, functionality and complex architectures.

This project has brought together a multi-disciplinary project team comprised of world leaders from CSIRO (the inventors of RAFT), the University of Washington, the O'Brien Institute at the University of Melbourne, and Australia's leading biomedical device company, Cochlear Ltd.

E.3 Impact Pathway

E.3.1 Project Inputs

The cash and in-kind support provided by the participants in the collaboration is shown in **Table E.1**.

E.3.2 Project activities

The RAFT project had three distinct research themes. Each of these is briefly described below.

Surface Modification (CSIRO with Cochlear and the O'Brien Institute)

This element of the project sought to develop polymer coatings that modify the surface of implantable materials, to enhance biocompatibility for biomedical device companies seeking a new technology to enhance existing or new products. Cochlear was interested in the technology because high performance coatings such as that possible with RAFT technologies could potentially provide advantages in terms of the body's response to implants.

TABLE E.1 CASH AND IN-KIND SUPPORT FOR THE RAFT PROJECT

Contributor / type of support	2011-12	2012-13	2013-14	2014-15	2015-16	2015-16	Total
Cash							
SIEF	$274,766	$1,125,234	$600,000	$1,000,000	$900,000	$100,000	$4,000,000
Cochlear Ltd		$150,000					$150,000
In-kind							
CSIRO	$276,515	$1,143,204	$1,187,777	$863,776	$1,337,107	$891,405	$5,699,784
University of Washington		$43,000	$43,000	$43,000			$129,000
Cochlear Ltd			$60,000	$60,000	$70,000		$190,000
O'Brien Institute			$145,000	$145,000	$145,000		$435,000
Total	**$551,281**	**$2,461,438**	**$2,035,777**	**$2,111,776**	**$2,452,107**	**$991,405**	**$10,603,784**

Therapeutic drug delivery

Conjugation of bioactives (CSIRO)

The objective of this research was to develop a polymeric scaffold for targeted drug delivery, through conjugation of both a cytotoxic small molecule drug and an antibody fragment. If successful, the technology could be used for the management of neoplastic disease (breast, prostate, colorectal, lung and other cancers), leading to more effective treatment outcomes. This research has sought to optimise the assembly of RAFT-based drug-loaded polymer antibody conjugates. It has included an exhaustive validation of the strategy in proof-of-concept preclinical studies. The successful demonstration of this approach would provide a point of leverage in the engagement of pharmaceutical and biotechnology companies to access the technology for the transition to a clinical development program.

Another activity, with Planet Innovation, involves a proof of concept study to assess the use of RAFT polymers for the development of immunohistochemistry (IHC) assays. The polymer is acting as a carrier or scaffold for a bioactive. IHC is an assay that detects the presence of proteins in biological tissues. For example a section of tumour is taken, and then sliced into a thin tissue section, IHC on this sample will lead to the detection of antigens in areas of tissue containing tumour cells, such as proteins that are known to be overexpressed at the surface of cancer cells. The areas that contain the protein that is being detected will be stained brown.

This work with Planet Innovation aims to improve the background/positive staining of the tissue section to ensure clear areas where the protein of interest is being detected, improvement over current system is required. Issues with current technology: non-specific binding of antibodies leading to unclear staining/cell delineation, leading to uncertainty in diagnosis, together with too low signal in the positive staining of tissues.

Delivery of therapeutic agents (CSIRO with the University of Washington)

A further activity, with the University of Washington was to develop a technology for the preparation of polymers that act as a prodrug[57] for the delivery of therapeutic agents. If successful, the results of this activity would provide new polymer reagents for transfection.[58] The path to market is less well defined for this application, and more discussions are required with partners for this aspect of the project. The potential commercial partners would be pharmaceutical companies.

57 A prodrug is a medication that, after administration, is metabolized (i.e., converted within the body) into a pharmacologically active drug.

58 Transfection is the process of inserting genetic material, such as DNA and double stranded RNA, into mammalian cells. The insertion of DNA enables the expression, or production, of proteins using the cell's own machinery.

E.3.3 Project outputs

The outputs of each of the three streams of research in the RAFT project are discussed below.

Surface Modification

The research has produced some interesting and useful results, the outcomes do not, in themselves, have commercial potential. The knowledge gained from this work has however resulted in changes of direction for some of Cochlear's research, saving the company millions of dollars.

Conjugation of bioactives

A range of polymers have been developed that meet all the requirements for use in a biological setting (e.g. water soluble, stable, easy to prepare, no cell toxicity and do not elicit an immune response). Each of these polymer has been joined (conjugated) to a therapeutic antibody fragment, through a stable chemical bond. The result is receptor-targeted polymer conjugates, often referred to as "antibody conjugates".

Absorption, distribution, metabolism, excretion and toxicity studies have been undertaken in animal models. This enabled the work to progress to a study that involves the use of a RAFT polymer to act as a scaffold for drug conjugation, where the polymer acts as a carrier for the drug. The drug-loaded polymer contains a functional group and is conjugated to an antibody fragment. By adding a targeting agent to the polymer (the antibody fragment), the conjugate should give rise to an increase in tumour targeting by receptor-mediated delivery.

Cytotoxic drug-loaded polymers have been prepared with an appropriate functional group for conjugation to antibody fragments. The cytotoxic drugs are attached to the polymer via cleavable linkers such that the free cytotoxic drug can be released at the site of action.

The work with Planet Innovation aims to use a RAFT polymer to stabilise the secondary antibody (perhaps preventing non-specific binding) and stabilise in terms of solubility, perhaps also promoting specificity by directing binding to the primary antibody selectively. This would increase the sensitivity of the assay by having multiple enzymes that are responsible for production of the brown colour in the assay, to be conjugated to each antibody (through the polymer).

Innovation / commercialisation generated

Surface Modification

The CSIRO research with Cochlear as a partner has allowed the company to focus their attention more on generating the innovation that they need to maintain and build their global competitiveness as well as to expand their market. However the SIEF-funded research has not generated outcomes that can be commercialised.

Conjugation of bioactives

The results of the research on drug-loaded polymer-antibody fragment conjugates has been tested in animals to determine their effectiveness as a cancer treatment. This tumour efficacy animal study has just been completed and is now in the report writing phase. The results provided by the company performing the study are good. The results show that drug-loaded polymer-antibody fragment conjugates are effective in reducing tumour burden and keeping the tumours negligible beyond completion of the injection regimen. Low dose multi-drug-loaded polymer-antibody fragment conjugates perform better in this anti-tumour efficacy study than antibody alone, drug-loaded polymer alone and polymer-antibody conjugates with only one drug loaded per polymer.

The work with the University of Washington has resulted in a provisional patent for intracellular delivery of proteins using RAFT polymers designed for endosomal escape (PCT Int. Appl. (2016), WO 2016025747 A1 20160218 "Nonlinear Copolymers as intracellular delivery vehicles and Related Methods", Feb 18, 2016).[59] The University of Washington, is involved in establishing a spin out company which could provide the commercialisation path for this technology.

[59] An endosome is a membrane-bound compartment inside eukaryotic cells.

The work with Planet Innovation, if successful, is likely to produce more immediate outcomes. Very similar co-polymers can be used for this project as for the SIEF RAFT project. Lessons learnt in the bioconjugation of RAFT polymers to antibody fragments will be used by Planet Innovation to conjugate the polymer to the secondary antibody used in the IHC assay (chemistry and purification techniques).

The Planet Innovation assay would be used by surgeons to determine whether or not there is cancer is a tissue sample and, if so, the assay will help inform the best treatment route. The test will also enable earlier detection of cancer, leading to a greater treatment success rate. This can work for tumours (solid and soft) but not for fluid cancers like leukaemia.

RAFT polymers are being used as scaffolds to increase the loading of the enzyme that is responsible for the assay's signal. The RAFT polymer will be conjugated to the secondary antibody, and will align the antibody to maximise readout. If successful, this will result in improved test accuracy for pathology laboratories and clinicians, significant cost savings to the laboratories and consumers as a result of quicker turn around with a more accurate test.

E.3.4 Project Outcomes

The outcomes of the RAFT project are expected to primarily consist of economic and social benefits.

In the case of Cochlear the results of the RAFT project have enabled the company to refocus its research on improving competitiveness and growing the market for the firm. There is a very strong bond of trust between Cochlear and CSIRO. Cochlear believes that CSIRO is one of the few research groups with both the necessary research expertise but also a good understanding of the commercial imperatives facing the private sector. The firm has made it quite clear that it would be very willing to work with CSIRO in the future should the need arise.

The Planet Innovation assay is expected to result in a new medical test. This work is currently six months into proof of concept stage, with further development at least another year away. The improved IHC assays could be used in Planet Innovation's current working kits.

Publications

There have been several significant publications and a number of conference presentations arising from this SIEF project. Some of the more significant ones include:

"*Enhancement of MHC-I Antigen Presentation via Architectural Control of pH-Responsive, Endosomolytic Polymer Nanoparticles*", John T. Wilson, Almar Postma, Salka Keller, Anthony J. Convertine, Graeme Moad, Ezio Rizzardo, Laurence Meagher, John Chiefari, and Patrick S. Stayton, AAPS J. 2015, 17, 358-369

"*Inhibition of protein and cell attachment on materials generated from N-(2-hydroxypropy l) acrylamide*", B.D. Fairbanks, H. Thissen, G. Maurdev, P. Pasic, J.F. White, L. Meagher, Biomacromolecules 15 (2014) 3259-3266

"*Biomedical Applications of Polymers derived by reversible addition fragmentation chain transfer (RAFT)*", Fairbanks BD, Gunatillake PA, Meagher L., Adv Drug Deliv Rev. 2015 91:141-52

Helmut Thissen presented an invited keynote lecture at 5. Asian Biomaterials Congress (ABMC5), entitled "*Advanced biomedical device coatings for effective control of the biological response*" (06.05.-09.05.2015) in Taipei, Taiwan.

Graeme Moad presented an invited talk at Pacifichem, The International Chemical Congress of Pacific Basin Societies, Hawaii, USA, in December 2015; in the Precision Polymer Synthesis symposium. Entitled "*Approaches to RAFT synthesis of multifunctional, multi-armed polymers – Stars in therapeutic delivery*".

Almar Postma presented an invited talk at the 13th International Nanomedicine & Drug Delivery Symposium (NanoDDS) 2015, Seattle, USA in September 2015, entitled "*Polymer Architectures for Vaccine Delivery*".

E.3.5 Adoption

If the results of the research on bioactive conjugates become the basis for successful medical treatments, the lead time is likely to be at least five years. In the case of a successful diagnostic test being developed in collaboration with Planet Innovation, the implementation time could be as short as two years.

E.3.6 Impacts

The expansion of RAFT into the multi-billion dollar medical and pharmaceutical sectors will position Australia at the forefront of biomedical materials research.

Surface Modification

Cochlear has reported that the SIEF-funded work has resulted in changes to its research program, saving the company millions of dollars.

Conjugation of bioactives

The research into the conjugation of bioactives could prove to be a powerful tool in the treatment of a range of different cancers and other medical conditions. The possibility of treating cancer with RAFT technology is at least five years away. The worldwide incidence of these cancers and the ranking of their prevalence is shown in **Table E.2**

TABLE E.2 WORLDWIDE CANCER STATISTICS

Rank	Cancer	New cases diagnosed in 2012
1	Lung	1.8 million
2	Breast	1.7 million
3	Colorectal	1.4 million
4	Prostate	1.1 million

SOURCE: WORLD CANCER RESEARCH FUND INTERNATIONAL

The RAFT project's research offers the potential for:

— Developing new polymers that can carry many different drugs and can be armed with a disease-targeting biomolecule allowing tailor made therapies thus increasing their efficacy.

— Enhancing current therapies by specifically homing-in on diseased cells and delivering multiple drugs to destroy diseased cells and leave normal cells alone, reducing undesirable toxicity.

— Mimicking biology by enhancing the delivery of drug inside the cells where the action occurs, allowing the drug to last longer thus reducing visits to the doctor

— Developing new diagnostic systems, medical imaging, wound care, and scaffolds for regenerative medicine, creating a greater armoury for treatments across a breadth of medical applications.

The use of RAFT chemistry in polymer-drug-antibody conjugates is well on the way towards proof of concept. After proof of concept, the timeframe and additional activities needed to achieve the ultimate intended impact are beyond the scope of this SIEF project. A clinical development program would require one or more pharmaceutical industry partners and a budget in the hundreds of millions of dollars.

What has been achieved by the end of the SIEF project is validation, *in vivo*, of a strategy for the effective treatment of malignant disease using a novel drug targeting approach. This should create a strong IP position that will facilitate licensing opportunities with biotechnology/pharmaceutical companies to take the work into clinical development program, providing a return on the SIEF investment in the form of upfront payments, and royalties.

ADCs are attracting considerable attention. However assembling an antibody, cytotoxin and linker, and manufacturing such products is proving challenging. One product that was granted fast track status in the US approval process has now been withdrawn. Some 45 ADCs are reported to be currently in clinical development.

The ADC market was reportedly worth $US454 million in 2013. With the imminent launch of several more ADCs, the ADC market is expected to grow to around $US3.5 billion by 2019.[60]

If the RAFT technology proves successful in the development of effective ADCs, and fast track approval is available, RAFT based ADCs could be available for limited applications from 2022.

In Australia, cancer treatment accounts for about a third of the financial cost of the disease. Other costs relate to lost productivity.[61] However it would appear premature to attempt to estimate the productivity benefits to Australians from the use of ADCs.

The Planet Innovation results will, if successful be used by surgeons to determine whether or not there is cancer is a tissue sample and, if so, to help inform the best treatment route. The test will also enable earlier detection of cancer, leading to a greater treatment success rate.

We do not have sufficient information to attempt to estimate the benefits from the application, with the University of Washington, of RAFT technology for therapeutic agents.

E.4 Clarifying the Impacts

E.4.1 Counterfactual

For all aspects of the work carried out in this project, SIEF funding has been of critical importance. Biomedical research typically requires one to two decades to bring a new treatment to market. Increasingly, biomedical and pharmaceutical and biotechnology companies require that pre-clinical data is obtained before they review technologies for possible funding or acquisition. Given the risk profile of the work and the development timeframes typical for biomedical applications, it is most unlikely that this work could have been funded from other sources — either internally at CSIRO, in partnership with other research providers, or by private sector investment.

E.4.2 Attribution

The attribution of impacts from the research undertaken to date are:

— For the RAFT-conjugated bioactives; SIEF 100%

— For the RAFT therapeutic agents: SIEF 80%, University of Washington 20%.

Both these components of the SIEF project draw on earlier work by CSIRO and the IP arising from that work. In addition, there will need to be significant further research and investment before these technologies reach the market. This could dilute the shares of attribution to SIEF and the University of Washington.

E.5 Evaluating the Impacts

E.5.1 Cost-Benefit Analysis

Costs

SIEF funding for this project was as follows: $0.275 million in 2011-12, $1.125 million in 2012-13, $0.600 million in 2013-14, $1.000 million in 2014-15, $0.900 million in 2015-16 and $0.100 million in 2016-17.

Benefits

According to Access Economics (2007)[62], the lifetime costs of cancer in Australia of all persons diagnosed with cancer in 2005 was $94.6 billion (or $125.29 in 2016-17 dollars after adjusting for inflation).

Assuming that the economic costs of cancer grow at the same rate as Australia's population, the costs of cancer in Australia in 2016-17 are estimated to be $149.22 billion. The future costs of

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60 Roots Analysis 2014, *Antibody Drug Conjugates Market (2nd Edition) 2014-2024*

61 *Cost of cancer in NSW – a report for the Cancer Council of NSW*, Access Economics, 2007.

62 Access Economics (2007), *Cost of Cancer in NSW*, report for The Cancer Council NSW, April.

cancer in Australia are then projected based on the growth rate of the population aged 50 years and above in the ABS' Series B (Medium) population projections.

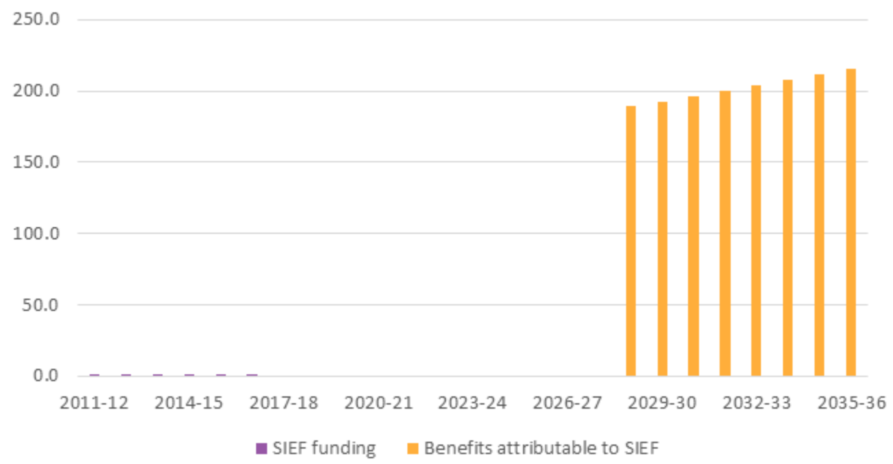
ACIL Allen has used the projected growth rate of the population aged 50 years and above rather than the growth rate of the entire population, as most cancers (like many medical conditions and diseases) tend to be more prevalent among older persons.

It is conservatively assumed that the SIEF-funded RAFT research in relation to medical applications results in a 0.01% reduction in the costs of cancer from 2018-19 onwards, and that all the resulting benefits are attributable to SIEF.

Assessment of benefits against costs

The costs and benefits of the project to 2035-36 are shown in **Figure E.2**

FIGURE E.2 RAFT PROJECT COSTS AND BENEFITS BY YEAR TO 2035-36 ($M, 2016-17 DOLLARS)



SOURCE: ACIL ALLEN

The present value of SIEF funding is $4.80 million in 2016-17 dollars under a 7% real discount rate. The present value of all project benefits is $53.24 million in 2016-17 dollars under the same discount rate.

Under ACIL Allen's conservative assumptions, the net present value (NPV) of the project is $48.44 million in 2016-17 dollars under a 7% real discount rate. The benefit-cost ratio (BCR) of the project is 11.08.

Sensitivity analysis

The BCR of the project:

— Increases to 110.85 if the impact of the SIEF-funded RAFT research on the future costs of cancer in Australia is 0.1% instead of 0.01%.

E.5.2 Potential future impacts

There may also be future benefits from CSIRO's collaboration with the University of Washington. We understand that discussions are underway with venture capitalists to form a spin off company to commercialise the research outputs.

E.5.3 SIEF's role as an Innovation Catalyst

The research team's work on using RAFT technology as a mechanism for the delivery of therapeutic agents is world leading and at the forefront of this relatively new field of research.

E.5.4 Distribution effects on users

The beneficiaries from this research include pharmaceutical companies and patients.

E.5.5 Externalities or other flow-on effects on non-users

Cochlear's decision to change its research direction as a result of its collaboration with the research team could lead to it being able to focus on areas of research that will help it to maintain or increase its market share.

F

CASE STUDY: SYNCHROTRON SCIENCE

BOX F.1 SYNCHROTRON SCIENCE - EXECUTIVE SUMMARY

Key findings

Three of the projects undertaken as a result of SIEF's support for the Synchrotron have been examined and the following potential benefits identified:

- Sampling of eucalypt leaves collected on the surface could save the cost and the time involved in drilling unnecessary exploration wells and could lead to improved gold exploration success rates.
- Persons suffering from a blood disorder could have access to an improved treatment option.
- The milk industry could have access to more efficient milk production and processing practices that would enable them to produce better quality milk products.

Innovation impact

SIEF-supported synchrotron projects have led to innovations and are resulting in some commercialisation activity. However it will take some time for commercial outcomes to be delivered.

SOURCE: ACIL ALLEN

This case study uses the evaluation framework outlined in the CSIRO Impact Evaluation Guide. The results of applying that framework to the synchrotron case study are summarised in **Figure F.1**.

F.1 Purpose and audience for case study

The Trustee of SIEF, together with SIEF's Advisory Council, may from time to time identify activities that align with the Purpose and Strategic Objectives of SIEF but that are outside the scope of SIEF's normal support programs. These activities generally represent funding gaps in the National Innovation System. Support to address such gaps can be provided under the SIEF Special Research Program (SRP).

This case study describes the economic, environmental and social benefits arising from SIEF's funding for the SIEF Special Research Program Synchrotron Science (SIEF identifier number SRP-01).

This information is provided for accountability, communication and continual improvement purposes. Audiences for this report may include Members of Parliament, Government Departments, SIEF, CSIRO, other researchers and the general public.

FIGURE F.1 SIEF SYNCHROTRON SCIENCE – IMPACT FRAMEWORK DIAGRAM

INPUTS	ACTIVITIES	OUTPUTS	OUTCOMES	IMPACTS
– SIEF investment – In-kind support from CSIRO and other PFRAs – The Australian Synchrotron	– PFRA research – Synchrotron operations	– Results of research – Publications – 2015 Victoria Prize for Science and Innovation – Five patents	– Possible take up by business – Potential for increased economic activity through commercialisatio n – Possible licencing fees – Potential for new products and services	– Improved sustainability – Better environmental or social outcomes – Fewer deaths or injuries – Increased international trade – Employment growth – Contribution to GDP

SOURCE: ACIL ALLEN

F.2 Background

Synchrotron science has revolutionised experimental techniques since the late 1970s. For many years, Australian researchers used overseas synchrotrons but, with demand for beam time often exceeding availability and the cost of international travel, it became clear that for Australia to remain internationally competitive in this field of research, Australian researchers needed a national facility.

In June 2001 the Victorian Government announced its decision to build a national synchrotron facility on land adjacent to Monash University. Construction of the Australian Synchrotron began in 2003. In January 2004 the then Victorian Minister for Innovation announced that the University of Melbourne, Monash University, Australian Nuclear Science and Technology Organisation (ANSTO) and CSIRO would each provide $5 million towards nine initial beamlines planned for the Australian Synchrotron.

In June 2007 the Commonwealth and Victorian Governments agreed that each would provide $50 million in operating funds for the period to June 2012. The New Zealand Government also committed to contribute operating funds. Synchrotron operations commenced in July 2007. It is now serving the needs of the wider research community, providing a platform for leading edge research and development across a wide spectrum of science and technology, from medicine to manufacturing.

In 2012, with the imminent expiry of the funding arrangements referred to above, CSIRO, acting on behalf of the Commonwealth Publicly Funded Research Agencies (PFRAs), coordinated a response to an invitation by SIEF to submit a proposal for a four-year Special Research Program (SRP) for PFRA scientists to use the synchrotron for research that aligned with the SIEF's Strategic Objectives. Five PFRAs participated in the proposal, with CSIRO the proposed Administering Organisation. The five Agencies were:

— The Australian Nuclear Science and Technology Organisation (ANSTO)

— CSIRO

— The Defence Science and Technology Organisation (now Defence Science and Technology Group)

— Geoscience Australia

— The National Measurement Institute

In the four-year period 2012-16 SIEF funding has supported 243 synchrotron projects. All but thirteen of these projects have been led by CSIRO. The majority of CSIRO-led projects have involved research collaboration partners from universities, medical research institutes and other research organisations. PFRA researchers have also participated in many other synchrotron projects, led by other collaboration partners.

F.3 Impact pathway

F.3.1 Program inputs

The SIEF Synchrotron SRP funding was part of a $100 million agreement with the Australian Government, ARC, the Victorian and New Zealand Governments and ANSTO to support Australian Synchrotron operations for a four year period. Under this agreement, each party was to receive proportional access to time on beamlines on the basis of their contribution. The SIEF SRP contributed a total of $10.23 million of this, with $10 million from the SIEF and $0.23 million from CSIRO.

For the SIEF-funded research projects that have used the Synchrotron, the in-kind inputs of CSIRO and other research partners cannot readily be estimated due to the often multi-faceted nature of research where synchrotron studies are but one component. However, it is certain that in-kind inputs corresponding to the time of researchers would have been considerable.

CSIRO researchers have also made in-kind contributions to the operations of the Australian Synchrotron through the time they have contributed by serving on peer review and management committees. Again, it is not possible to estimate the value of this time.

TABLE F.1 INPUTS TO THE SIEF SYNCHROTRON PROGRAM

Contributor / type of support	2012-13 $ million	2013-14 $ million	2014-15 $ million	2015-16 $ million	Total $ million
Cash					
SIEF	2.5	2.5	2.5	2.5	10.0
CSIRO				0.23	0.23
Grand Total					**10.23**

F.3.2 Program activities

The SIEF Synchrotron Science SRP activities have included:

- Providing beam time access to researchers
- Making contributions to Synchrotron governance and management

The SIEF Synchrotron Science SRP has performed well in delivering access to the Synchrotron for the PFRAs. The socio-economic objectives for the research that has been supported through SIEF ranged across a number of codes. Where these codes have been identified by the researchers, they included:

- Mineral resources (34 projects)
- Health (27 projects)
- Manufacturing (37 projects)
- Energy (30 projects)
- Animal primary products (5 projects)
- Plant primary products (6 projects)
- Environment (5) projects
- Culture (1 project).

Synchrotrons provide intense x-ray beams that can be used in many ways to study many types of samples and phenomena, from proteins to paintings, from nanostructures to engine casings. Each of many different techniques used at the synchrotron has special, often unique, instrumentation and dedicated specialist staff. Examples of projects from the first three of the above groups are discussed below.

Minerals industry application of synchrotron research

Researchers at the Australian Synchrotron have used the innovative Maia detector for X-ray Fluorescence Microscopy (XFM) for the detailed chemical mapping and analysis of mineral samples. XFM is used across a wide range of geology and geochemical disciplines to study ore deposition and improved technologies for mineral processing. One such study that has captured international attention is the discovery that some species of desert eucalypts and acacias concentrate traces of economically important metals, especially gold, in their leaves as a by-product of their deep-rooted search for water and nutrients in hostile desert environments.

Newspaper headlines referring to 'Gold in Gum Leaves' have not reflected the significance of this discovery: Australia has an ancient landscape, with much of its geology covered by deep layers of eroded material. Mineral exploration in many parts of Australia is made more difficult and expensive because of the nature of this deep cover. By demonstrating that nano-particles of gold that have been sequestrated in leaves by desert plants are actually signatures of deeply buried ore bodies, and not, for example wind-blown dust particles, the CSIRO team has used the synchrotron to open a whole new field of bio-geological mineral exploration technologies with which new major ore bodies may be discovered.[63]

Medical application of synchrotron research

Synchrotrons play an important role in the study of biochemicals and the development of new pharmaceuticals. The Australian Synchrotron has several beamlines dedicated to the analysis of proteins and other molecules using x-ray diffraction to determine their precise structure. As an example, with the help of CSIRO's Collaborative Crystallisation Centre, the Cooperative Research Centre for Cancer Therapeutics (CRC-CTx) has developed a compound that binds to and inhibits *arginine methlytransferase 5* (PRMT5) proteins which are implicated in both cancer and non-cancer blood disorders affecting millions of people. This compound is now licenced, through Australian company Bionomics Ltd, to MSD, an Australian arm of the multinational drug company Merck. High levels of PRMT5 are found in mantle cell lymphoma, chronic lymphocytic leukaemia, melanomas, and lung and breast cancers and are linked to low survival rates. PRMT5 inhibitors switch on important genes in the development of blood, which could provide disease-modifying treatment options for patients with blood disorders like sickle cell disease and beta thalassemia.

Primary industry and manufacturing application of synchrotron research

A team from the CSIRO’s Food and Nutrition group has used the Australian Synchrotron to examine the nanostructure of casein micelles, a protein structure found within components of cow’s milk, to identify how it can be manipulated for more efficient milk processing practices and better quality milk products. This research was conducted in partnership with the Victorian Government Department of Economic Development, Jobs, Transport and Resources. Investigating micellar behaviour at the nanoscale through the Australian Synchrotron was crucial to the research team’s efforts to devise improvements for Australia’s milk processing industry.

By better understanding micelle formation in cow’s milk, researchers can improve the way milk is processed into different products and stored to maintain quality. This is particularly important to support the milk export industry that transports products such as milk powder and cheese to growing Asian markets.

F.3.3 Program outputs

Publications

Over the four years of SIEF Synchrotron Science SRP funding the SIEF-supported program produced 260 publications up to 18 September 2016. Of these, citation data was available for

63 Radford N 2016, personal communication to CSIRO

206 publications which had been cited a total of 1495 times with an h index[64] of 7.29 for this group. The most cited journal article was a review that had been cited 74 times. It should be remembered that many of the publications arising from SIEF funding of the synchrotron are relatively recent, so further citations can be expected.

Five patents relating to work involving the Australian Synchrotron have been filed by CSIRO.

Awards

Professor Calum Drummond was awarded the 2015 Victoria Prize for Science and Innovation in the Physical Sciences category. Professor Drummond is currently Deputy Vice-Chancellor Research and Innovation at RMIT, although the prize was awarded for work that he did while at CSIRO. It honours his contribution in advancing the understanding of key factors involved in molecular assembly and particle and surface interactions in liquids.

Innovation / commercialisation

SIEF-supported synchrotron projects have led to innovations and are resulting in some commercialisation activity. However apart from the drug to treat blood disorders, it will take some time for other research results to be commercialised.

F.3.4 Program outcomes

The Australian Synchrotron is a tool that facilitates research. The synchrotron component is usually only one element of this research. Research projects that have used the synchrotron as part of their research are likely to generate outcomes over time. The main beneficiaries are expected to be industry and the general public.

SIEF-supported synchrotron projects have the potential to provide a wide range of economic, social and environmental benefits. Because there have been a large number of these projects, it has not been possible to undertake a comprehensive analysis of the outcomes. Furthermore, for many of the projects undertaken it is still too early to be able to judge their eventual outcomes.

Below we have considered the outcomes of the three projects discussed above.

Gold in eucalypt leaves

Sampling of eucalypt leaves collected on the surface saves the cost and the time involved in drilling unnecessary exploration wells. More than $740 million was spent in the search for gold in Australia in 2012. Some 44% of minerals exploration projects in Australia are primarily focussed on gold. Most of Australia's near-surface gold is likely to have been discovered but exploration has taken place over only about 20% of our land mass to date, suggesting that there is considerable scope for further exploration. Australia's annual gold production is around 250 tonnes and, at a price of around $40,000 per kilogram, this amounts to $10 billion per annum. If this research resulted in even a small improvement in exploration cost efficiency or contribution to the development of new mines, the benefits would be significant.

Drug to treat blood disorders

The initial payment from MSD to Bionomics is in excess of $21 million and potential payments are expected to exceed $700 million. The majority of revenues will be returned to CTx and its Australian research partners. There will also be additional funded collaboration between MSD and CTx on blood disorders.

Structure of casein micelles in milk

In Australia, dairy is a $13 billion farm, manufacturing and export industry. There are 6,700 dairy farmers and together, they produce around 9.5 billion litres of milk a year with a pre-market value of $4 billion (before costs such as storage, transport and marketing are applied). The Australian dairy industry directly employs 43,000 Australians on farms and in factories, while more than 100,000 Australians are indirectly employed in related service industries. The results of this research will facilitate increased production, employment and exports of milk-based products.

64 The h index is a measure of both the productivity and citation impact.

F.3.5 Adoption

We have assumed that adoption of the gold-in-eucalypt-leaves as an exploration tool grows steadily over the next ten years. Savings from reduced drilling costs increase gradually over that time. For the purposes of this case study we have assumed that total production could increase over the next ten years to be 10% greater by the end of that period and that savings in the cost of exploration in that period would be 10% of the 2012 figure (i.e. $74 million per annum).

The authors of this case study are not privy to the details of the licencing agreement for the new drug to treat blood disorders. It can normally take some time for a new drug to reach the market. After that time, the blood disorder drug could have a high adoption rate. We have therefore assumed that the flow of license fees will start at $20 million in 2020 and increase by $20 million per annum over the next ten years.

We have assumed that the lead time for adoption of the results of the work on casein micelles would be two years. After that, we have assumed that the pre-market value of exported milk products will be greater, on average, over the next ten years by 10% (i.e. $400 million per annum).

F.3.6 Impacts

The impacts of the three examples discussed above could be significant:

— Gold exploration success rates could improve.

— Persons suffering from a blood disorder could have access to an improved treatment option.

— Milk processors could have access to more efficient milk processing practices that would enable them to produce better quality milk products.

F.4 Clarifying the impacts

F.4.1 Counterfactual

As noted above, the four-year SIEF funding has supported 243 synchrotron projects. In this period more than 2000 projects were conducted at the Australian Synchrotron. Getting access at overseas facilities would be very difficult if not impossible for this many projects. In the absence of the SIEF contribution to the Australian Synchrotron, most of the research supported by SIEF would not have occurred or, at best may have taken place with some significant delays through Australia's limited access to other synchrotrons. Performing experiments at overseas synchrotrons requires a longer planning period, greater uncertainty, higher costs, and much less effective collaboration.

The availability and accessibility of the Australian Synchrotron has encouraged PFRA researchers to undertake some ambitious research activities.

However, because it is possible that the research projects discussed above could have been done using overseas synchrotrons we have assumed that this would have delayed the results by four years. It is also likely that if the researchers had relied on overseas synchrotrons that this would have diluted the benefits to Australia.

F.4.2 Attribution

SIEF funding enabled access to the Australian Synchrotron by researchers from PFRA's. Without this funding PFRA researcher access would only be by collaboration with other research institutions that were part of the funding package or by paying for access time on a case by case basis. Based on data from the Australian Synchrotron showing the extent of commercial access and the level of collaborative access for CSIRO compared to direct access it can be estimated that around 70% of the project impacts can be attributed to the existence of the SIEF funding, with the balance shared between CSIRO and other PFRAs.

F.5 Evaluating the impacts

F.5.1 Cost benefit analysis

Costs

SIEF funding for the synchrotron project was: $2.5 million in 2012-13, $2.5 million in 2013-14, $2.5 million in 2014-15 and $2.5 million in 2015-16.

Benefits

Gold in eucalypt leaves

We assume that $740 million is spent on searching for gold in Australia each year, the same as the actual amount that was spent in 2012. We then assume that, when fully adopted, the exploration tool derived from the SIEF-funded research will enable a 5% reduction in annual exploration costs.

Finally, we assume that the adoption rate is 20% in 2017-18, 40% in 2018-19, 60% in 2019-20, 80% in 2020-21, and 100% from 2021-22 onwards. In addition, it is assumed that 25% of the resulting benefits can be attributed to SIEF.

Drug to treat blood disorders

It is assumed that the initial licensing fees received from MSD in 2020-21 is $20 million. The licensing fees then increase by $10 million per year in real terms until they reach $130 million in 2031-32. They remain at that level thereafter.

It is assumed that 25% of the licensing fees received from MSD are attributable to SIEF.

Structure of casein micelles in milk

As noted previously, the current pre-market value of milk production in Australia is approximately $4 billion a year. It is assumed that the value of Australian milk production grows by 2% a year in real terms, and that the SIEF-funded research enables a 1% increase in milk production and exports each year.

Again, it is assumed that 25% of the resulting benefits are attributable to SIEF.

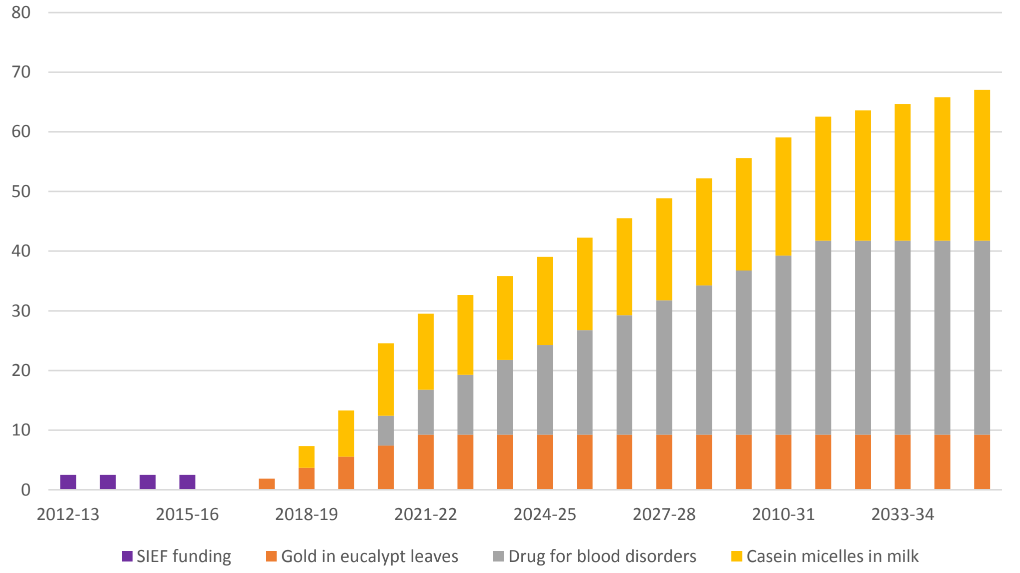
Assessment of benefits against costs

The costs and benefits of the project to 2035-36 are shown in **Figure F.2**.

The present value of SIEF funding is $11.88 million in 2016-17 dollars under a 7% real discount rate. The present value of all project benefits is $811.2 million in 2016-17 dollars under the same discount rate.

The net present value (NPV) of the project is therefore $799.3 million in 2016-17 dollars under a 7% real discount rate. The benefit-cost ratio (BCR) of the project is 68.2.

FIGURE F.2 SYNCHROTRON COSTS AND BENEFITS BY YEAR TO 2035-36 ($MILLION IN 2016-17 DOLLARS)



SOURCE: ACIL ALLEN

Sensitivity analysis

The BCR of the project:

- Decreases to 61 if the SIEF-funded research reduces the annual costs of gold exploration by 2% instead of 5%.
- Increases to 91.4 if the licensing fees received from MSD increases by $20 million a year between 2021-22 and 2031-32 instead of $10 million a year.
- Increases to 168.94 if the SIEF-funded research enables a 5% increase in annual milk production and exports instead of a 1% increase.

F.5.2 Potential future impacts

There are a large number of synchrotron research projects that have occurred as a result of the SIEF support provided for that research infrastructure. It is possible that some of the projects will deliver benefits. However, the precise nature and timing of those potential benefits is not known.

F.5.3 SIEF's role as an innovation catalyst

SIEF-supported synchrotron projects have led to potential innovative approaches in minerals exploration and milk production.

The possible new drug to treat blood disorders is assumed to take a little longer before it is commercialised.

F.5.4 Distribution effects on users

The beneficiaries of this project include gold exploration companies, milk producers, processors and exporters and persons suffering from specific blood disorders.

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EARLY CAREER RESEARCHER SURVEY QUESTIONS

The questions developed by CSIRO for their survey of early career researchers supported by SIEF are listed below.

1. Please provide your name.
2. Please provide your email address.
3. Are you an Early Career Researcher or a Mid Career researcher?
4. How would you rate the advice you received from other researchers while working on the SIEF project? (on a scale from 1 (extremely low) to 5 (extremely high))
5. How would you rate the mentoring you received from other researchers while working on the SIEF project? (on a scale from 1 (extremely low) to 5 (extremely high))
6. Did the SIEF project assist you in developing collaborations? (on a scale from 1 (extremely low) to 5 (extremely high))
7. Did the SIEF project assist you in developing industry linkages? (on a scale from 1 (extremely low) to 5 (extremely high))
8. Did the SIEF project assist you in developing mobility (short to mid-term scientific visits to other research organisations? (on a scale from 1 (extremely low) to 5 (extremely high))
9. Did the SIEF project provide you with training and development in technical areas? (on a scale from 1 (extremely low) to 5 (extremely high))
10. Did the SIEF project provide you with training and development in non-technical areas (e.g. critical thinking, project management, statistical analysis, communication, teamwork, commercialisation, IP financial management)? (on a scale from 1 (extremely low) to 5 (extremely high))
11. Did the SIEF project help you identify career pathways in research and/or other areas?
12. Did the SIEF project experience help you get further employment (another role, project or contract)?
13. Overall did the SIEF project help you progress your career as an ECR? (on a scale from 1 (extremely low) to 5 (extremely high)).

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