ACIL ALLEN

24 November 2022

Report to IMCRC

The Impact of the IMCRC

An independent end of operation report

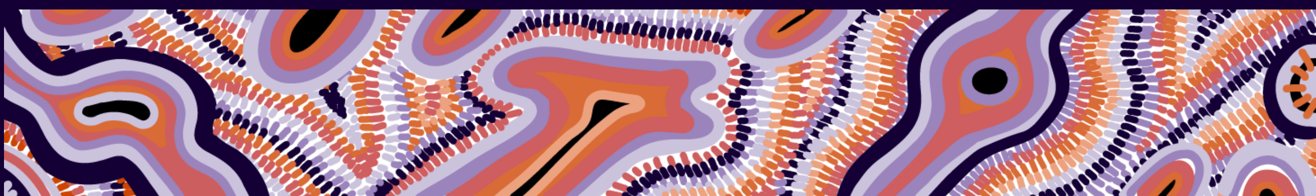
About ACIL Allen

ACIL Allen is a leading independent economics, policy and strategy advisory firm, dedicated to helping clients solve complex issues.

Our purpose is to help clients make informed decisions about complex economic and public policy issues.

Our vision is to be Australia's most trusted economics, policy and strategy advisory firm. We are committed and passionate about providing rigorous independent advice that contributes to a better world.

ACIL Allen acknowledges Aboriginal and Torres Strait Islander peoples as the Traditional Custodians of the land and its waters. We pay our respects to Elders, past and present, and to the youth, for the future. We extend this to all Aboriginal and Torres Strait Islander peoples reading this report.



Goomup, by Jarni McGuire

Contents

Contents

Contents

Figures

Tables

Contents

Boxes

IMPACT of the IMCRC

IMCRC inputs

$35 million
cash contribution of IMCRC

CBA results

(7% discount rate in 2021-22 dollars) analysed over 2016-17 to 2029-30:

$172 million
Net Present Value

1.8 BCR

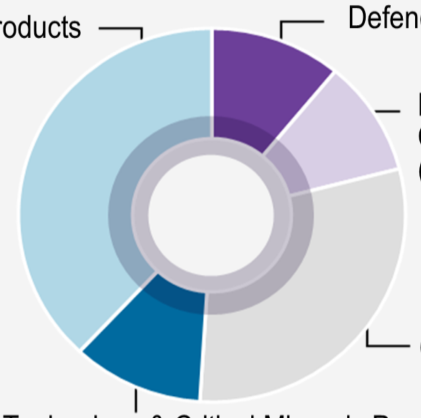
IMCRC has provided support to
71 projects
in total

Leveraged inputs

$35 million
cash contribution from industry

$144 million
in-kind contributions from industry and universities

IMCRC project funding by manufacturing sector



OTHER BENEFITS OVER 2016-17 TO 2029-30

6,089
ongoing FTE by 2029-20

45
postgraduate completions

224
collaborations and partnerships

181 cases of industry partners trialling and adopting new technology over 2016-17 to 2029-30 – areas of investment include machine learning/artificial intelligence, robotics and automation, advanced materials, sensors and data analytics, virtual or augmented reality, and additive manufacturing/3D printing

22 new businesses and new business opportunities

$2 billion of future R&D investment planned by industry partners

Over **750** manufacturing SMEs involved in futuremap™ workshops, which showcased IMCRC's business maturity diagnostic tool

Executive summary

It is a requirement of the Cooperative Research (CRC) Program that CRCs coming to the end of their operations provide the Government with an independent end of operation evaluation report. To meet this requirement the Innovative Manufacturing CRC (IMCRC) commissioned ACIL Allen to undertake an evaluation to assess the impacts of the CRC and to communicate to others in industry and the research community the significant benefits that are possible through collaborative research.

For the purposes of this evaluation, ACIL Allen has undertaken a cost benefit analysis (CBA) of the full portfolio of projects supported by the IMCRC (see Box ES 1). The data used for this analysis is that provided to IMCRC by each project team. In addition, six projects were selected to be developed as case studies. The case studies probe the outcomes and impact of those six projects in greater detail.[1]

Box ES 1 Explanation of the CBA methodology

A CBA involves a systematic evaluation of the impacts of a project or program, accounting for all the effects on the community and economy, not just the immediate or direct effects, financial effects or effects on one group. This approach is consistent with best-practice CBAs as recommended by the Commonwealth Government Office of Best Practice Regulation, as well as state government Treasury Departments. Taking a best-practice CBA approach ensures that government decision makers have a consistent basis on which to assess the impacts of projects and programs.

Since the CBA analyses the impacts of the IMCRC from the perspective of society as a whole, the cash and in-kind support leveraged by the IMCRC's investment are included as costs. In effect, this means that the IMCRC's success in leveraging additional cash and in- kind support has a direct impact on the benefit cost ratio (BCR) of projects.

A CBA used by government is different to analysis undertaken by a business considering an investment. A business normally considers only its own costs. External 'costs' such as funding provided through government grants or co-investment would not be included in their calculations. Although this is appropriate from a business perspective, it is a different exercise from the CBA used by the Australian Government.

ACIL Allen considers that the significant in-kind support leveraged by the IMCRC should be viewed as an achievement, and one which contributed to the expected significant future benefits identified and projected by firms that were supported by the IMCRC.

Source: Office of Best Practice Regulation and ACIL Allen

Table ES 1 Shows the estimated net present values (NPVs) and benefit cost ratios (BCRs) of each of the six case studies. It also shows the results of the benefit cost analysis for all the IMCRCs

[1] Please note that the detailed results for one of the projects selected as a case study (Boral) are not provided in this report as they are commercially sensitive.

projects in total. The results show that the six case studies delivered benefits in excess of their costs. This is also true of the IMCRC as a whole.

Obviously, with projects involving research and development, the outcomes are inherently uncertain. There are likely to be some projects that ultimately deliver benefits that are significantly higher than might have been initially estimated by the project teams. Equally, others might be unsuccessful and fail to deliver any benefits. In addition, the period over which we have examined potential benefits is relatively short, and it is possible that additional benefits will be delivered in the longer term.

Furthermore it is important to recognise that CRCs are designed to support multi-year (medium to long term) research projects, ideally with multiple parties. Projects that fit well within manufacturing often tend to have longer R&D lead times, especially those in highly regulated industries such as medical technology, defence, etc. Thus much of the most significant and transformative impact from CRCs is likely to become evident in the long term. In particular, many benefits might only be realised beyond the timeframe used in this evaluation (up to 2029-30).

The analysis done of the projects selected as case studies suggest that the estimated benefits of those projects (see Table ES 1) are robust lower bounds and that, in some cases, the actual benefits are likely to be significantly higher. It is reasonable to expect that the same will be true of other projects supported by the IMCRC. Importantly, the six projects used as case studies were primarily selected as examples of collaborative R&D, and not because of their potential financial impact.

Table ES 1 Estimated NPVs and BCRs for the IMCRC (7% discount rate)

Project	NPV	BCR
Lava Blue	$3,399,543	1.29
FormFlow	$12,567,559	21.11
Monitum (Kurloo)	$34,152,858	7.76
Codex Bioreactor	$15,674,675	3.35
Whiteley Corporation	$7,205,057	2.16
All 5 case studies	$72,999,691	3.42
All IMCRC projects	**$171,490,402**	**1.8**

Source: ACL Allen

Note: The figures the Boral case study are not included in the table above due to their commercial sensitivity.

The estimated BCR for the IMCRC as a whole is 1.6. As noted above, we anticipate that this number is based on a conservative estimate of benefits (achieved and projected) and that the eventual benefits are likely to be greater. This would of course flow through to a higher BCR.

We note that the BCR would be significantly higher if analysis was performed from the perspective of the businesses that participated in the IMCRC, rather than using a CBA approach which considers costs and benefits from a societal perspective. From the perspective of the businesses that participated in the CRC, their investment was roughly $108 million ($35 million cash and $73 million in-kind) and the benefits they received were almost $4.2 billion (in 2021-22 dollars).[2]

While the economic benefits of the IMCRC are estimated to be significant, there are many other types of benefit delivered as a result of the support that has been provided. This includes:

[2] Note that the benefits do not include any spill over benefits that might flow through to the economy more broadly. Such second or third tier benefits are common, particularly in the manufacturing sector. For example, such higher order benefits can occur as other manufacturers adopt or adapt technologies that are similar to the ones developed.

- Social benefits such as:
  - employment opportunities (over 6,000 ongoing FTE by 2029-30)
  - education and training (45 postgraduate completions over 2016-17 to 2029-30)
  - increased levels of collaboration and new partnerships between researchers and businesses, including internationally (224 collaborations over 2016-17 to 2029-30)
  - the creation of new businesses and new business opportunities for existing firms (22 over 2016-17 to 2029-30)
  - investment in emerging technologies such as machine learning/artificial intelligence, robotics and automation, advanced materials, sensors and data analytics, virtual or augmented reality, and additive manufacturing/3D printing.
  - ongoing investment in R&D facilities that will help to drive future innovations (more than $2 billion over 2016-17 to 2029-30)
- environmental benefits such as
  - reduced GHG emissions (more than 3.38 million tonnes of CO_2 over 2016-17 to 2029-30)
  - improved environmental outcomes
  - more sustainable businesses that are better able to maintain their licenses to operate.

Several examples of social and environmental benefits have been identified from the IMCRC case studies. These demonstrate the real-world impacts delivered as a result of the work done by the projects that were supported by the IMCRC.

The stakeholders consulted over the course of this study were uniformly positive about the role played by the IMCRC in helping to ensure the successful delivery of their project. The fact that there were only three projects that failed to complete their planned research projects (only one was because the research failed) supports the argument that the level of engagement of the IMCRC in the projects that it supported was conducive to achieving the intended project outcomes. The high successful completion rate is particularly noteworthy given that much of the R&D was underway during the COVID pandemic. This supports the view that the IMCRC's assessment and selection process identified transformative projects of strategic value and genuine importance to the project partners. Furthermore the IMCRC's stage gated management of the projects provided early warning signals that helped to ensure that any challenges could be identified, managed and mitigated.

The IMCRC was somewhat different from many other CRCs in that the projects it supported were very largely identified and driven by industry. Indeed, research organisations were not eligible to apply for funding support as all projects had to be industry-led. This is not to suggest that the IMCRC had a laissez faire approach to its projects. In fact, it generally played an active role in the projects it supported. However, the IMCRC did this not by taking on any kind of day-to-day role in projects, but rather by implementing leading industry project management and reporting processes.

For example, during the assessment and selection process undertaken by an independent investment committee, the IMCRC often put forward suggestions to enhance project scopes and outcomes. These were generally agreed and built into project milestones. The IMCRC also used its contacts and understanding of the manufacturing sector to put project teams in touch with organisations and other businesses that could help to successfully deliver project objectives. This ranged from providing advice on engineering firms that could help build pilot plants, to linking project participants with business schools that could help them to understand the market for their product and develop business plans for commercialising their technology. As Robert Cohen, President, Digital, Robotics, and Enabling Technology at Stryker noted:

> *…the IMCRC industry-led model is not just distinct from a traditional CRC, but it is unique from a global perspective. IMCRC has strong governance and organisational structures that focus on commercial outcomes with consideration of efficiency of decision making and*

> *industry engagement. IMCRC is a true benchmark for engendering R&D collaboration between universities and manufacturers.*[3]
>
> *Robert Cohen, Stryker*

The IMCRC not only supported businesses through matching cash support that it awarded to firms to carry out their R&D projects and to fund expenditure at partner research organisation(s), but also assisted a much larger cohort of firms by providing access to futuremap®. This is a trademarked diagnostic tool and platform, which allows manufacturing SMEs to assess and understand their current state of maturity, as well as identify areas of focus and potential investment to transform and future-proof their business. Some 750 manufacturing SMEs, as well as many large and other businesses, participated in futuremap™ workshops between 2017-18 and 2020-21.

Finally, it is worth noting that the IMCRC responded well to the challenges caused by the COVID pandemic. Its response included launching the activate stimulus program. This program allowed Australian businesses to apply for smaller amounts of IMCRC funding ($50,000 to $150,000). This cash support was designed to support shorter term industry-led R&D projects that had lower starting barriers and required less financial commitment from all parties. The activate program effectively doubled the number of industry partners, particularly Australian SMEs, who could engage on projects with IMCRC research organisations.

[3] Innovative Manufacturing CRC (IMCRC) Annual Highlights 2019-20

Introduction 1

1.1 The Innovative Manufacturing CRC

The Innovative Manufacturing CRC (IMCRC) has helped Australian companies to increase their global relevance through research-led innovation in manufacturing products, processes and services. The IMCRC's vision is for Australian manufacturing to be thriving, relevant and globally integrated. The IMCRC was a not-for-profit, independent organisation, which helped Australian companies increase their relevance through collaborative, market-driven research in manufacturing business models, products, processes, and services.

In collaboration with companies, research organisations, industry associations, and government, the IMCRC has:

— Co-funded broad, multidisciplinary, industry-led research projects that delivered commercial outcomes

— Advanced the wider cause of manufacturing transformation through industry education and public advocacy.

The IMCRC operated at a time when manufacturing was entering a fourth industrial revolution. This transition offers vast opportunities for Australian companies to create new products and services, to expand into new supply chains and markets at home and around the world, and to attract and develop a new generation of skilled employees.

The IMCRC has aimed to encourage and help manufacturers to invest in collaborative research to exploit innovative technologies. It has promoted public perceptions of 'brand manufacturing' of capital-intensive, labour-intensive production facilities, to embracing the fourth industrial transformation, in which companies leverage digital technologies, including Industry 4.0, to develop intellectual property, technologies that value add, customisation and business models to sell new products and services to a global market.[4]

1.2 Purpose of the study

The IMCRC has reached the end of its CRC Program funding. Therefore it has commissioned ACIL Allen to undertake an impact analysis study to try to answer the following questions:

— What is the Government's and Industry's return on investment for IMCRC?

— Is IMCRC achieving its intended outcomes? What is the magnitude of the changes that occurred?

— To what extent has IMCRC increased the strength and quality of business-research collaboration in Australia?

[4] IMCRC 2022, website accessed on 28 September 2022 at https://www.imcrc.org/

- To what extent has IMCRC generated a culture of industry-research collaboration, with firms and researchers seeing value in collaborative partnerships?
- To what extent has IMCRC contributed to the competitiveness, sustainability and productivity of Australian manufacturing and supported commercial outcomes?
- Has IMCRC improved commercialisation and business performance?
- To what extent has IMCRC increased research training and improved the capability of the manufacturing research workforce?
- What are the intended and unintended outcomes achieved IMCRC relevant to the Government's strategic priorities?
- Are the IMCRC outcomes achieved to date in line with the Government's current and forward priorities?
- How well do IMCRC's participants match the intended target group and is the reach sufficient to realise the required scale of change?
- What are the main factors contributing to the outcomes?
- How much does IMCRC's outcomes contribute to economic growth (GDP), real consumption, real investment and taxation revenue?
- What is the level of satisfaction from those who participated in the CRC and examples of benefits they received and value from their involvement
- How well collaboration has improved competitiveness and productivity, including beyond the end of the CRC
- What unintended benefits resulted from the CRC
- What, if any, lessons can be drawn from IMCRC to improve the efficiency or effectiveness of future manufacturing research initiatives or programs?

1.3 Structure of this report

This report is structured as follows:

- Chapter 2 examines the IMCRC's role and its programs of work
- Chapter 3 reports the economic, social and environmental benefits identified in this impact assessment
- Chapter 4 discusses the six case studies which provide in-depth analyses of IMCRC's impacts
- Chapter 5 summarises the impact of the IMCRC and presents the conclusions from this study.

The IMCRC's Role and Activities 2

2.1 IMCRC objectives

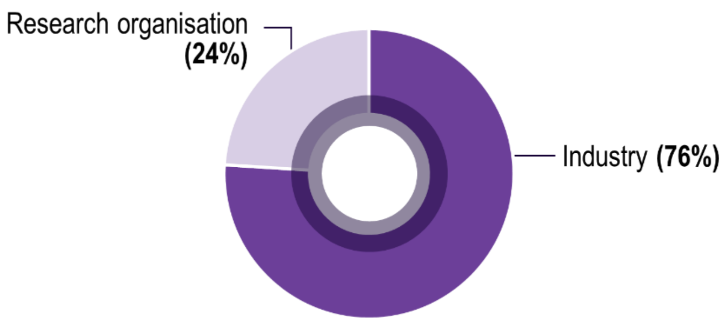
IMCRC is an independent and for-impact CRC with a successful, proven and scalable model for catalysing research and business partnerships that drives transformative commercial outcomes for participating Australian manufacturers. IMCRC has engaged with manufacturing SMEs throughout Australia, encouraging them to think differently about the opportunities and challenges that emerging digital technologies and business models pose for their business.

By supporting collaboration between businesses, research organisations, industry associations, and government, the IMCRC has sought to catalyse and invest in research projects that benefit the wider Australian manufacturing sector.

The IMCRC's approach differs somewhat from that of other CRCs. Its approach has been strongly commercial, and industry focussed. IMCRC's Board, management and programs are industry-led, and all projects supported have been applied for by industry. Projects have been resolutely industry-driven. More than three quarters of the projects were initially identified by industry (see Figure 2.1). As Robert Cohen noted:

> *…the IMCRC industry-led model is not just distinct from a traditional CRC, but it is unique from a global perspective. IMCRC has strong governance and organisational structures that focus on commercial outcomes with consideration of efficiency of decision making and industry engagement. IMCRC is a true benchmark for engendering R&D collaboration between universities and manufacturers.*[5]
>
> *Robert Cohen, President, Digital, Robotics, and Enabling Technology at Stryker*

Figure 2.1 Origin of idea or technology supported by IMCRC funding



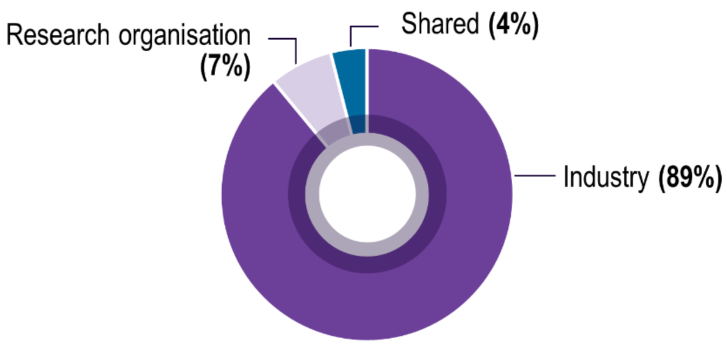
Source: IMCRC

[5] Innovative Manufacturing CRC (IMCRC) Annual Highlights 2019-20

The IMCRC has also often played a more active role in the projects it supported. However, it has not sought to take on any day-to-day involvement in projects. Rather, it has adopted a range of industry best practice project management and reporting processes for projects. IMCRC has used its contacts and understanding of the manufacturing sector to put project teams in touch with organisations and other businesses that could help to successfully deliver project objectives. This has ranged from introductions to other manufacturers and providing advice on engineering firms that could help build pilot plants, to linking the project participants with business schools that could help them to understand the market for their product and develop business plans for commercialising their technology.

Importantly, notwithstanding its close involvement in projects, the IMCRC has not sought to take any share in the ownership of any intellectual property (IP) that resulted from the projects it supported, whilst also ensuring that no future barriers would exist to commercialising any new IP created. The vast majority of the IP generated by the projects is owned by the industry partners (see Figure 2.2). No project IP is owned by the IMCRC. In IMCRC's view this ensures that any IP created rests with those best placed to commercialise it.

Figure 2.2 Ownership of IP generated by IMCRC projects



Source IMCRC:

The IMCRC's aim has been to help catalyse the transformation of the Australian manufacturing sector. A large component of this has involved engaging directly with manufacturing SMEs via the Industrial Transformation Program (see Section 2.5) to increase awareness of, and to catalyse investment in, Industry 4.0. However, an awareness of Industry 4.0 does not automatically enable application of Industry 4.0 technologies. For that to occur, firms (particularly Australian SMEs) need people who are skilled in those technologies, including at the leadership and management level. Hence the IMCRC's education and training activities have included seeking to build the manufacturing workforce of the future. To this end, the IMCRC has supported PhD scholarships, Master's degree candidates and internships in collaborative research programs. It has also included the development and deployment of a unique and proprietary SME education platform and diagnostic tool, futuremap®, which has helped raised awareness and catalyse investment across hundreds of Australian manufacturing SMEs.

Interestingly, notwithstanding the closer involvement between the IMCRC and the projects it has supported, project proponents that were consulted over the course of this study spoke very favourably about the reporting requirements that were imposed on them, describing these requirements as much less onerous and time consuming than those imposed by other government support programs.

Projects could be applied for by industry, commencing ideally at Technology / Manufacturing Readiness Level (TRL/MRL) 4 through to 7 or 8 – i.e. from a proof of concept through to readiness to scale up and commercialise.[6] Project milestones were determined and aligned to these readiness levels. This was instrumental in both planning and managing the success of the projects (see Appendix A).

To date, IMCRC has successfully co-invested in over 70 R&D projects in transformative manufacturing research, providing support through four separate Research Programs. In addition, during the COVID pandemic the IMCRC launched the activate program which allowed for less expensive, shorter-term projects to be funded under each of the four Programs. The IMCRC's Programs are described in the sections that follow.

2.2 Program 1 - Additive Manufacturing processes

Additive manufacturing, or 3D printing, is the fastest-growing sector of manufacturing around the world. The benefits offered by additive manufacturing include aiding companies to develop new products, reducing the time to bring products to market time to market, reduced waste during manufacturing, and lower product cost.

The key focus of Program 1 has been to assist firms to:

- develop and utilise existing and novel materials, process control, characterisation and surface engineering
- advance the use of additive systems, e.g. multi-material systems
- tailor additive manufacturing design including optimising the shape and topography and integrating creative design and additive process engineering.

Six larger projects were funded under Program 1. The IMCRC's support to these projects totalled over $6.7 million. That investment leveraged $32.2 million in other support, giving a funding ratio (ratio of IMCRC funding to total other support) of 4.74.

2.3 Program 2 - Automated and Assistive Technologies

Program 2 has supported projects that investigate a range of agile manufacturing technologies that can improve the performance and operational effectiveness of short run and personalised production systems. The aim of Program 2 has been to help firms develop:

- assistive robotics and support systems (e.g. vision) that provide real-time, physical support to the workforce
- automated technologies with perception and situational awareness capabilities that interact safely with their environment including other assistive technologies and the workforce across the manufacturing process
- distributive heterogenous collaboration technologies that enhance OH&S, skill augmentation and continuous quality control and assessment

Six larger projects were funded under Program 2. The IMCRC awarded support that totalled over $4.9 million. That investment leveraged $22.7 million in other support, giving a funding ratio (ratio of IMCRC funding to total other support) of 4.62.

[6] This stage of the innovation chain is often referred to as the 'valley of death'.

2.4 Program 3 - High Value Product Development

Advancements in digitisation, automation, and the increasing demand for mass customisation are driving the shift to Industry 4.0.[7] In view of this trend Australian manufacturers need to invest in and deploy new product innovations to future-proof their businesses.

Program 3 sought to assist Australian manufacturers to rapidly develop, produce, supply and support new products and technologies into international markets and supply chains. Examples include new electronic devices, diagnostic tools and implantable materials that utilise key enabling science and manufacturing technologies.

Nineteen larger projects were funded under Program 3. The IMCRC provided support that totalled almost $19 million to these projects. That investment leveraged $99.7 million in other support, giving a funding ratio (ratio of IMCRC funding to total other support) of 5.25.

2.5 Program 4 - Industrial Transformation

Program 4 aimed to advance the wider cause of manufacturing transformation through industry education and public advocacy. It sought to create and provide resources that particularly assist SME manufacturers to assess and adopt emerging digital technologies and new business models.

An important element of Program was the creation of the futuremap™ tool (see Box 2.1)

Box 2.1 The futuremap® tool

futuremap® is a business maturity diagnostic tool. It helps manufacturing SMEs to assess and understand their current state of maturity, as well as identify areas of focus and potential investment to transform and future-proof their business. futuremap® assesses participating businesses against thirteen key areas of industrial and manufacturing maturity and provides them pointers to the most productive focal points for improvement and gains for the business.

futuremap® has been delivered through two main mechanisms:

— a one-to-one format conducted by an accredited consultant/business adviser with the business' CEO or equivalent

— at facilitated events or workshops organised by the IMCRC or its deployment partners on a one-to-several basis. Deployment partners included the Commonwealth Government's Entrepreneurs' Programme and several IMCRC research organisation members. This enabled nationwide deployment using existing resources.

Source: IMCRC

Six projects were funded under Program 4. The IMCRC provided these projects with over $3.3 million in support. That investment leveraged $17.6 million in other support, giving a funding ratio (ratio of IMCRC funding to total other support) of 5.28.

As part of Program 4, the IMCRC also ran more than 100 futuremap ® workshops nationwide between 2017-18 and 2021-22. The majority of these were held face to face, but around 20 per cent were run on-line during the COVID pandemic lockdowns. Over 650 manufacturing SMEs have participated in the futuremap ™ workshops during this period. Many larger manufacturing businesses also participated in futuremap ™ workshops.

[7] Industry 4.0 refers to the fourth industrial revolution. It is the cyber-physical transformation of manufacturing. The name is inspired by Germany's Industrie 4.0, a government initiative to promote connected manufacturing and a digital convergence between industry, businesses and other processes.

As noted above, the IMCRC has also supported 110 PhD, Master's degree candidates and undergraduate students in their studies or to undertake internships over the course of its operations.

2.6 Activate program

In response to the challenges arising from the COVID pandemic, the IMCRC worked closely with all of its projects to help them overcome the disruptions associated with lock downs and stay on track with their work. This included designing and launching the activate program.[8]

This program effectively created a subset of projects under each of the other four programs. It allowed Australian businesses to apply for IMCRC funding support of between $50,000 and $150,000 to undertake shorter and faster industry-led R&D projects that had lower starting barriers, required less financial commitment, and could tap into existing resources within IMCRC partner research organisations.

There was considerable enthusiasm for these opportunities to support less expensive and more time-limited projects. A total of almost $3.5 million in activate support was awarded to 35 projects. That investment leveraged some $19.1 million in other cash and in-kind support, giving a funding ratio (ratio of IMCRC funding to total other support) of 5.47.[9]

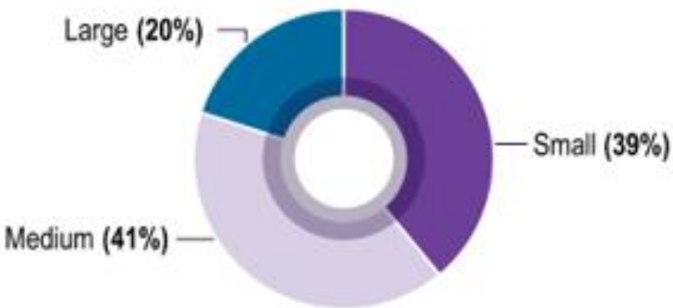
2.7 Overview of projects supported

2.7.1 Introduction

In total, the IMCRC has provided support to 71 projects in total. Overall, some $34 million has been provided in funding to these projects. This has leveraged over $172 million in investments by the participants in the projects. In other words, every dollar of IMCRC support leveraged almost $5.06 in support from project participants.

Eighty per cent of the support provided to industry participants in the projects was to Australian owned SMEs (see Figure 2.3) and almost a quarter of these were regional firms (see Figure 2.4).

Figure 2.3 Proportion of IMCRC support by company size

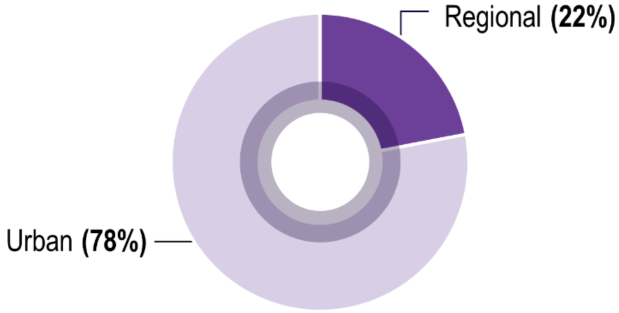


Source: IMCRC

[8] The IMCRC also maintained close contact with the project teams that it had provided support for and was flexible in dealing with delays and project adjustments that were caused by the COVID pandemic.

[9]Note that the funding and leveraged value of activate projects are also included in figures of programs 1 through 4 (they are not additional).

Figure 2.4 Industry partners by location

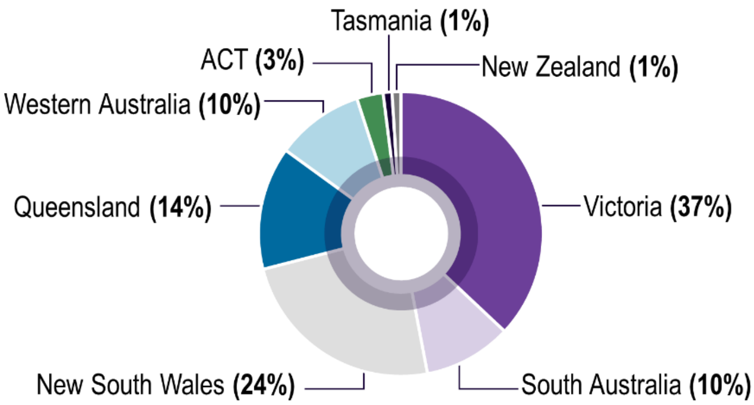


\

Source: IMCRC

The industry partners of the projects that supported were spread widely around the country (see Figure 2.5).

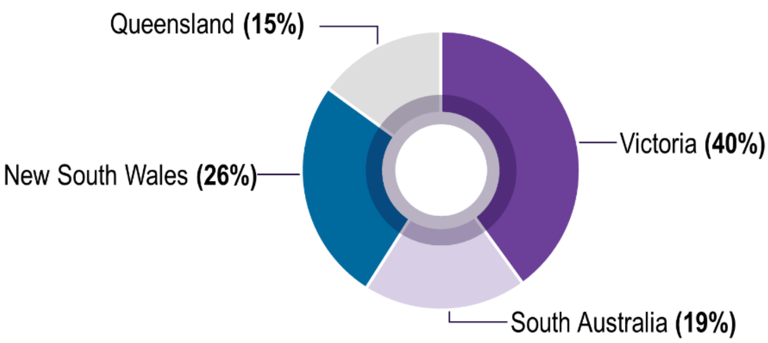
Figure 2.5 Industry partners by jurisdiction



Source: IMCRC

The research partners for the project were concentrated in the eastern states. For example, Figure 2.6 shows that some two thirds of IMCRC's funding went to projects where the research partner was located in either Victoria or NSW.

Figure 2.6 IMCRC funding by research partner location



Source: IMCRC

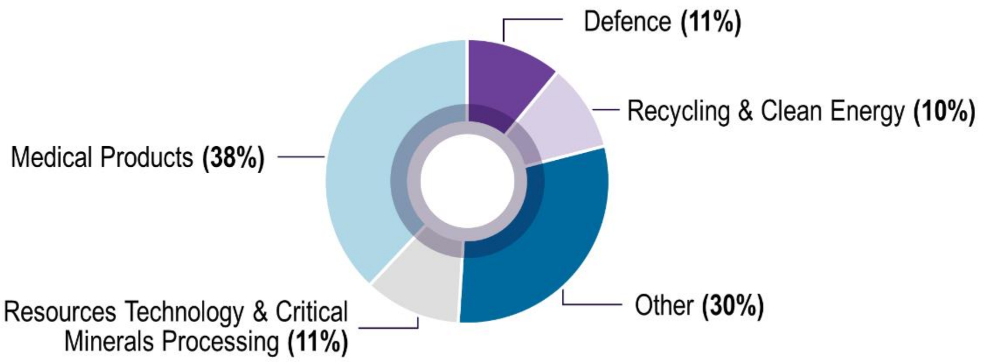
2.7.2 IMCRCs alignment with national priorities

In 2020 the Commonwealth Government identified six areas as National Manufacturing Priorities, namely:

— Resources technology and critical minerals processing
— Food and beverage
— Medical products
— Recycling and clean energy
— Defence
— Space

Over two thirds of the funding provided by the IMCRC was for projects that were in the sectors that had been identified as National Manufacturing Priorities (see Figure 2.7).

Figure 2.7 IMCRC project funding by National Manufacturing Priority sector



Source: IMCRC

The Commonwealth Government's 2014 Industry, Innovation and Competitive Agenda (IICA) aimed to position industry to build innovation capacity, commercialise and apply emerging technologies, and increase productivity.[10] The aim was to secure Australian industry's competitive standing in the global economy. The IICA identified four overarching ambitions to achieve these aims, namely:

— a lower cost, business-friendly environment with less regulation, lower taxes, and more competitive markets
— a more skilled labour force
— better economic infrastructure
— industry policy that fosters innovation and entrepreneurship.

The Industry Growth Centre Initiative (IGCI) was established to be the centrepiece of this Agenda.[11] It was designed on the principle that government is best placed to coordinate policy and programs to achieve impact within and across sectors, and industry is best placed to drive cultural change and overcome barriers to innovation, productivity and growth.[12]

[10] Commonwealth of Australia, 2014, *Industry Innovation and Competitiveness Agenda: An action plan for a stronger Australia*. Canberra.

[11] Commonwealth of Australia, 2014, *Industry Growth Centres Prospectus*. Canberra.

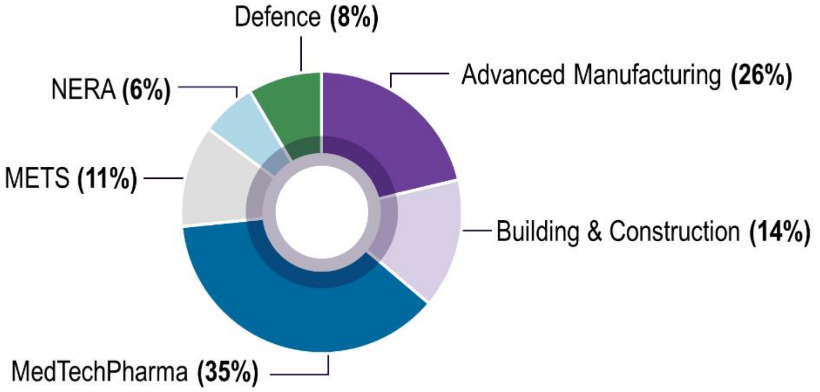
[12] Department of Industry, Science, Energy and Resource, 2020, Industry Growth Centres. Accessed 30 September 2022: https://www.industry.gov.au/strategies-for-the-future/industry-growth-centres .

Six industry sectors were selected to receive support under the initiative namely:

— Advanced Manufacturing (known as the Advanced Manufacturing Growth Centre (AMGC))
— Cyber Security (known as AustCyber)
— Food and Agribusiness (known as Food Innovation Australia Limited (FIAL))
— Medical Technologies and Pharmaceuticals (known as MTPConnect)
— Mining Equipment, Technology and Services (known as METS Ignited)
— Oil, Gas and Energy Resources (known as National Energy Resources Australia (NERA)).

Figure 2.8 shows how IMCRCs project funding maps across the six industry growth centre sectors. The bulk of the IMCRCs support flowed to firms in the medical technology and advanced manufacturing. However, businesses from all six sectors received some funding.

Figure 2.8 IMCRC funding by IGCI sector



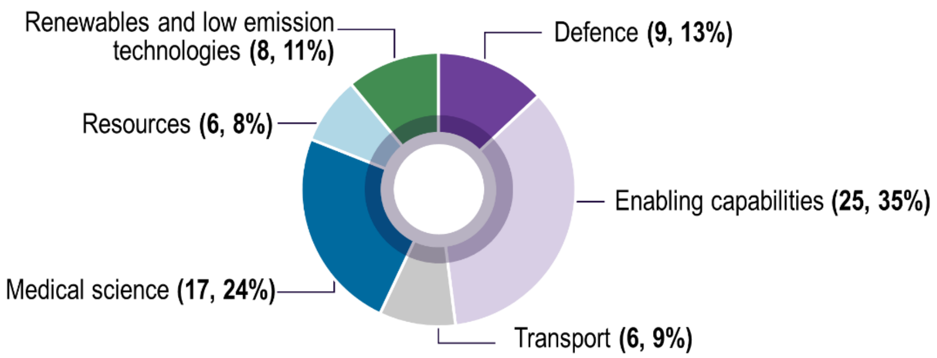
Source: IMCRC

In 2022 the current Government identified the following sectors as being key ones for the nation:

— Defence
— Enabling capabilities
— Transport
— Medical sciences
— Resources
— Renewables and low emission technologies

As can be seen from Figure 2.9, IMCRC's funding support continues to align well with these six sectors.

Figure 2.9 Number of IMCRC projects by sector



Source: IMCRC

Benefits of the IMCRC 3

This chapter describes the economic, social, and other benefits of the IMCRC projects over the period from 2016-17 to 2029-30. It should be noted that more benefits from the IMCRC may well be realised beyond 2030, particularly for longer term research in higher regulated sectors such as medical, health and defence. The data that underpins the analysis of benefits was reported to the IMCRC by industry project participants. The section on economic benefits includes a summary of the cost-benefit analysis, which found that the Net Present Value (NPV) of the IMCRC is expected to be over $171.5 million at a seven percent discount rate (benefit-cost ratio of 1.8).

This chapter also describes the social benefits which include additional employment opportunities, education and training, new businesses created, and increased collaboration. Other benefits discussed include reduced greenhouse gas emissions, increased uptake of emerging technologies, as well as the catalysing effect of IMCRC in the innovation ecosystem.

Note that the estimated benefits do not include any spill overs that might flow through to the economy more broadly. Such second or third tier benefits are common, particularly in the manufacturing sector. For example, such higher order benefits can occur as other manufacturers adopt or adapt technologies that are similar to the ones developed, or as savings to the government from delivering better health outcomes.

3.1 Economic benefits

A cost-benefit analysis (CBA) was conducted to estimate the economic benefits of the IMCRC. To undertake this analysis, a counterfactual scenario (a scenario with no IMCRC) and a reference case (a scenario with an IMCRC) was used to estimate the benefits arising from the IMCRC. To undertake the analysis a number of assumptions have had to be made. These included adjusting the data to take into account the proportion of benefits could be attributed to IMCRC, as well as allowing for Selling, General and Administrative Expenses (SG&A) when estimating the revenue generated from IMCRC projects. A description of the counterfactual scenario, reference case and the assumptions made in the CBA is provided in Appendix B.

The summary of the CBA and sensitivity testing of the results is provided in the following sections.

3.1.1 Cost benefit analysis summary

A summary of the results of the CBA with a seven per cent discount rate is in Table 3.1 below. All figures have been converted to 2021-22 dollars for the analysis.[13]

The total costs of IMCRC projects amounted to $214,451,366. These costs include cash contributions from the IMCRC and industry partners (35 per cent), non-staff in-kind costs (23 per

[13] Consumer Price Index reported by the Australian Bureau of Statistics was used to convert reported figures to 2021-22 dollars.

cent) and staff in-kind costs (42 per cent).[14] Examples of non-staff in-kind costs include the use of research facilities and equipment.

Table 3.1 CBA results 2016-17 to 2029-30 (in 2021-22 dollars with a 7 per cent discount rate)

Source	
Present value costs	
Cash contributions (IMCRC + Industry)	$75,068,330
Non-staff in-kind contributions (Cash Equivalent)	$49,794,901
Staff in-kind contributions (Cash Equivalent)	$89,588,135
Total costs	***$214,451,366***
Present value benefits (attributed to IMCRC)	
Cost Savings	$81,405,598
Cost Avoidance	$6,971,817
Additional Revenue	$270,633,891
Customer Savings and Efficiencies	$26,930,462
Total benefits	***$385,941,768***
Net Present Value and BCR	
Net Present Value	$171,490,402
BCR	**1.8**

Note: The CBA did not take into account the value of the reduction in GHG emissions
Source: ACIL Allen cost-benefit analysis based on figures reported to IMCRC by project partners

The total benefits of IMCRC projects attributable to IMCRC amounted to $385,941,768. These benefits consisted of cost savings (21 per cent), cost avoidance (2 per cent), additional revenue (70 per cent) and savings and efficiencies for customers (7 per cent). Detailed descriptions of these benefit categories are provided in Appendix B.

The NPV of IMCRC projects attributable to the IMCRC is $171,490,402. The benefit-cost ratio is 1.8. A BCR above one suggests that the benefits of the IMCRC are expected to outweigh the costs of the IMCRC, and the investment has led to a net positive result.

ACIL Allen believes that the CBA analysis presented above is likely to provide a conservative estimate of IMCRC's impact. The main reason for this is that many of the estimated benefits of projects occur in the future and the precise level of those future benefits is uncertain. The outcomes of our analysis may have been influenced by impacts from the COVID pandemic, both in terms of the timeframes for generating a return from the R&D, and potentially some pessimism about making the investments required to commercialise R&D outcomes.

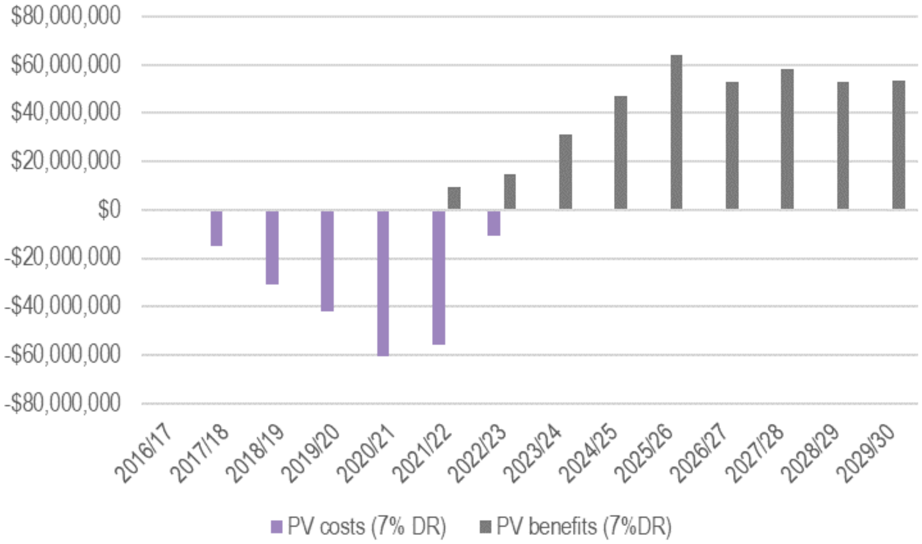
Understandably, project teams tend to adopt a relatively conservative approach when they report the estimated benefits of their projects to the IMCRC. ACIL Allen's more detailed examination of six projects featured in the case studies for this report identified a number of projects where we believe the initial estimates of benefits reported to IMCRC are likely to be highly conservative. For example, while the estimated BCR for the Lava Blue project is more than one, it should be noted that there has already been a licence agreement signed to build a commercial scale plant using Lava Blue's technology. This could be producing a product worth around $100 million a year. The benefits of

[14] Note that the value of the staff in-kind costs is the cash equivalent for salaries calculated at Commonwealth determined rates at the establishment of IMCRC.

the Lava Blue project are therefore likely to be significantly higher than we have estimated based on the information provided to IMCRC.

The total flow of costs and benefits by year is shown in Figure 3.1 below. It should be noted that benefits are expected to continue, beyond the analysis period used in this evaluation (2016-17 to 2029-30).

Figure 3.1 Present value of IMCRC project costs and benefits from 2016-17 to 2029-30 (2021--22 dollars at 7 per cent discount rate)



Source: ACIL Allen cost-benefit analysis based on figures reported to IMCRC by project participants

The majority of the costs have already been incurred (69 per cent of costs were incurred in 2020-21 or earlier), while a majority of benefits are expected in occur in the future (97 per cent occur from 2022-23 onwards).[15] Note that the benefits appear to spike in 2025-26, before falling slightly in 2026-27. The data showed that this is likely due to some project participants reporting benefits only to 2025-26, and not providing any estimates of benefits beyond that year. No estimates of benefits beyond 2029/30 were provided by participants. However, ACIL Allen expects that benefits would continue to be delivered beyond that date.

3.1.2 Sensitivity analysis

Sensitivity analysis of the discount rate was also conducted as per Commonwealth Government best practice CBA guidelines.[16] The seven per cent rate is the discount rate recommended by the Commonwealth Government for best-practice CBA, with the three and 10 per cent rates included as sensitivity tests. The results of the CBA show that the net impact is positive at all three discount rates (see Table 3.2 below).

[15] This is important to note for sensitivity testing of the discount rate in the CBA, as we can expect that a higher discount rate will lower the NPV (the PV of past costs will increase, and the PV of future benefits will decrease at a higher discount rate).

[16] Refer: https://obpr.pmc.gov.au/resources/guidance-assessing-impacts/cost-benefit-analysis

Table 3.2 Sensitivity testing at 3, 7 and 10 per cent discount rates

	3% discount rate	7% discount rate	10% discount rate
Present value costs	$196,497,122	$214,451,366	$245,703,824
Present value benefits	$507,565,992	$385,941,768	$272,019,743
Net Present Value	**$311,068,870**	**$171,490,402**	**$26,315,919**
BCR	**2.6**	**1.8**	**1.1**

Source: ACIL Allen cost-benefit analysis based on figures reported to IMCRC by project partners

Since a majority of costs are in the past and a majority of benefits in the future, there is a significant difference in the NPV of IMCRC projects when comparing results at the three per cent and 10 per cent discount rate (the NPV is over 10 times greater at the three per cent discount rate than the 10 per cent discount rate). Having a positive BCR at the 10 per cent rate shows that the IMCRC's impacts are resilient to significant changes in the discount rate.

For this analysis, ACIL Allen has assumed that Selling, General and Administrative (SG&A) expenses would account for 25 per cent of additional revenue, based on average SG&A costs for manufacturers (see Appendix B for more information on the basis for this assumption). Sensitivity testing was conducted on the proportion of revenue that would be spent on SG&A (see Table 3.3 below).

Table 3.3 Sensitivity testing of SG&A costs at 10, 25 and 40 per cent of additional revenue (7 per cent discount rate)

	SG&A is 10% of revenue	SG&A is 25% of revenue (central case)	SG&A is 40% of revenue
Net Present Value	**$222,935,928**	**$171,490,402**	**$120,044,876**
BCR	**2.0**	**1.8**	**1.6**

Source: ACIL Allen cost-benefit analysis based on figures reported by IMCRC

Table 3.3 shows that increasing and decreasing SG&A by 15 per cent compared to the central case has a significant impact on the NPV. If SG&A is only 10 per cent of revenue, the NPV is 30 per cent higher than the central case. When SG&A is 40 per cent of revenue the NPV is 30 per cent lower than the central case. Since the industry partners of IMCRC come from a range of sectors, it is difficult to predict the exact proportion of revenue that SG&A would account for. However, this sensitivity analysis shows that the result is positive even when SG&A accounts for a higher proportion of revenue than the manufacturing sector average.

3.2 Social benefits

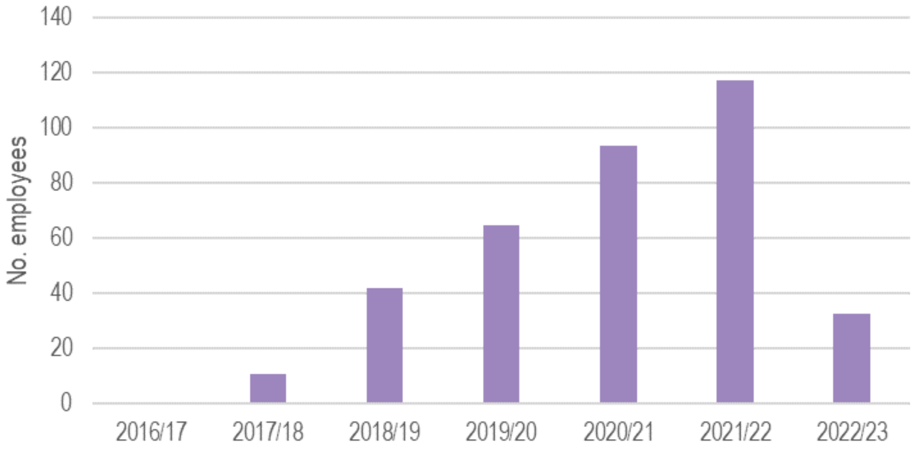
Social benefits reported by IMCRC project participants include employment opportunities, new businesses and service models, education and training, and partnerships and collaborations. The figures represent the total benefits achieved by the companies as a result of the projects.

3.2.1 Employment opportunities

The IMCRC's activities have led to additional employment opportunities in the industry and university sectors.

Figure 3.2 shows the number of researchers at universities directly employed and whose salaries were paid for by the IMCRC supported projects. The number of researchers employed at universities as a result of IMCRC projects rose from 11 in 2017-18 to 117 in 2021-22. The number is expected to fall to 33 FTE in 2022-23. This is because the IMCRC is reaching the end of its funding period and therefore fewer researchers will be directly employed on IMCRC-supported projects (most IMCRC projects ended by September 2022). The total number of FTE job-years created in the university sector over the analysis period as a result of the IMCRC's support is estimated to be 361.[17]

Figure 3.2 Employment of researchers in university sector by year



Source:

Figure 3.3 below shows the additional employment opportunities created by industry partners as a result of the project. The employment of researchers in Figure 3.3 differs from those in Figure 3.2 because the former shows the number of researchers employed by industry partners rather than by the universities.

Ongoing employment opportunities created by the projects supported by IMCRC are estimated to increase from 33 FTE in 2021-22 to 6,089 FTE in 2029-30.[18]

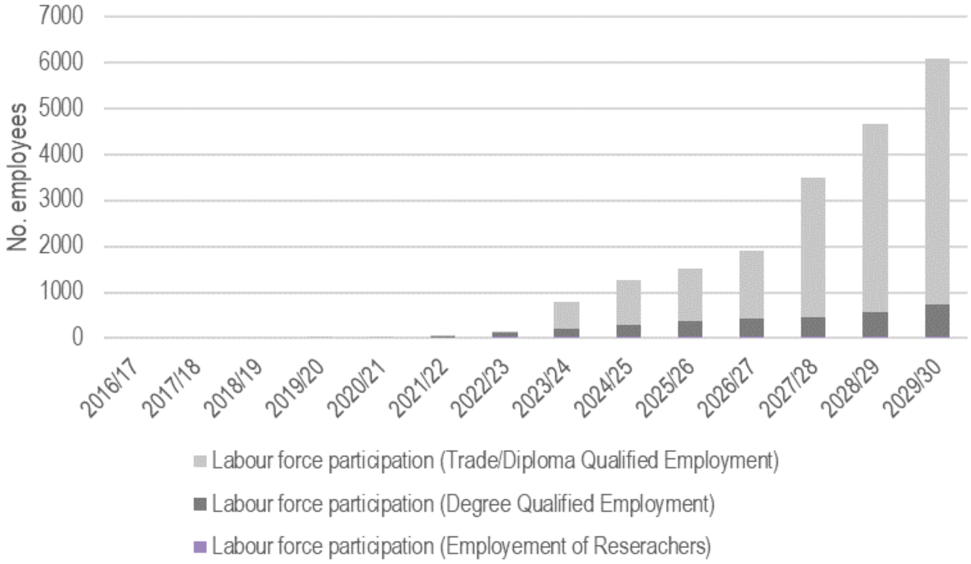
In 2021-22, 37 per cent of the 33 FTEs were university researchers, 54 per cent were degree qualified, and 9 per cent were trade or diploma qualified. In 2029-30, of the 6,089 ongoing FTE, 1 per cent are expected to be university researchers, 11 per cent are expected to be degree qualified, and 88 per cent are expected to be trade or diploma qualified. This reflects a significant expected shift in industry partners' demand for staff trained at the trade/diploma level in future years as the technology moves from the research stage through to the commercialisation stage. The total number of FTE job-years created over the analysis period as a result of the IMCRC is estimated to be 19,880 job-years.[19] For example, The Lava Blue project is estimated to create around 61 new full-time jobs by 2030 and some 140 job-years over the analysis period.

[17] An FTE job-year is equivalent to one person employed full time for one year. For example, if one person worked full time for five years, that is equivalent to five FTE job-years.

[18] Note that there is a small number of ongoing FTE prior to 2021-22 (approx. 7 ongoing FTE).

[19] FTE job-years counts the total amount of time employed. If one ongoing FTE worked for five years, that is equivalent to five FTE job-years. It measures the total time worked across staff rather than the number of staff.

Figure 3.3 Employment by industry partners by employee type by year



Source: ACIL Allen based on figures reported to IMCRC by project partners

3.2.2 New businesses

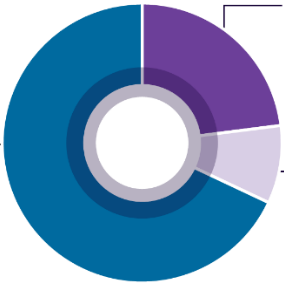
A total of 22 new businesses or business models are expected to result from IMCRC projects at this time. ACIL Allen notes that more benefits may result as commercialisation of the research progresses beyond the IMCRC's term. Figure 3.4 below shows the breakdown of the new businesses and service models by type over the analysis period (2016-17 to 2029-30). Of these, 15 (68%) are new service models, 2 (9%) are start-ups and 5 (23%) are spin-off companies. Examples of service models include software as a service, data management, monetization, design services, and contracted R&D.

The number of reported new businesses is likely to be a lower bound figure. For example, it does not include the proposed High Purity Alumina plant that Queensland Pacific Metals proposes to construct based on Lava Blue's technology.

Similarly, ACIL Allen's consultations with FormFlow identified that their IMCRC project has led to new business opportunities including modular building systems to deliver high quality, affordable housing. The company has used their technologies to deliver a range of housing solutions to address, among other things, bushfire resilience, and rapid response disaster relief housing. FormFlow advertises a number of potential designs on its website, which includes studios and modular housing with customisable bedroom and bathroom capacity.

The Monitum project has led to a new firm being spun off (Kurloo). Kurloo's business model includes an initial cost for the on-the ground monitoring hardware, coupled with an ongoing service that monitors movements and warns clients when it occurs.

Figure 3.4 Breakdown of new businesses by type over analysis period (2016-17 to 2029-30)



Source: ACIL Allen based on figures reported by IMCRC

3.2.3 Education and training

A total of 21 post graduate students (PhD or master's students) were supported by IMCRC over the analysis period. Importantly, ACIL Allen is aware of a number of these students that have gone on to work for the firms that participated in the projects they were involved in during their studies. In our experience, such interchanges between the research and industry sectors can prove vital in commercialising and realising the benefits of R&D.

In addition, IMCRC have also supported scholarships for an additional nine Master's degrees by Coursework students, which included facilitating a 6-month industry project as part of their studies. Cash matching was also provided by IMCRC to support 24 Australian Postgraduate Research Intern PhD students with manufacturing-related projects in industry. Nine of these PhD students have completed their studies, with the remaining 15 to complete their PhD later this year or in future years.

3.2.4 Partnerships and collaborations

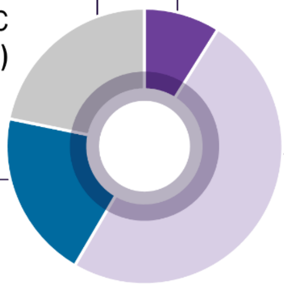
There have been 224 existing and planned partnerships and collaborations reported over the analysis period (2016-17 to 2029-30). Figure 3.5 below shows the breakdown of partnerships and collaboration by type over the analysis period.

Of the planned partnerships and collaborations over the analysis period, 20 (9%) are Australian partnerships, 111 (50%) are Australian collaborations, 44 (20%) are international collaborations, and 49 (22%) are further collaborations planned with IMCRC research partners.

Further collaborations with IMCRC research partners are expected to occur in the future (2022-23 onwards). The continuation of these collaborative arrangements beyond the end of the IMCRC's support is a clear indication of the strength of the relationships that have developed over the projects' duration. It also demonstrates that the parties recognise the value of the collaboration and wish to continue it.

For example, the Lava Blue case study shows that the research partner has taken a significant equity in the industry partner in the project and continues to work closely with it.

Figure 3.5 Breakdown of partnerships and collaborations by type over analysis period (2016-17 to 2029-30)



Source: ACIL Allen based on figures reported by IMCRC

Codex has an ongoing collaboration with Sydney University that is expected to be mutually beneficial. Codex will sell the bioreactor while the University will use it as a research tool to carry out research that has the potential to generate significant medical advances. Publication of the University's research results is expected to lead to further sales of the bioreactor to other research groups.

The Boral project provides another example of successful collaboration facilitated by the IMCRC. Boral reports that the IMCRC strengthened the UTS-Boral partnership significantly. Boral has stated that IMCRC not only enabled stronger collaboration between Boral and the UTS School of Civil and Environmental Engineering, but also facilitated the partnership between Boral and the UTS Business School.

3.3 Other benefits

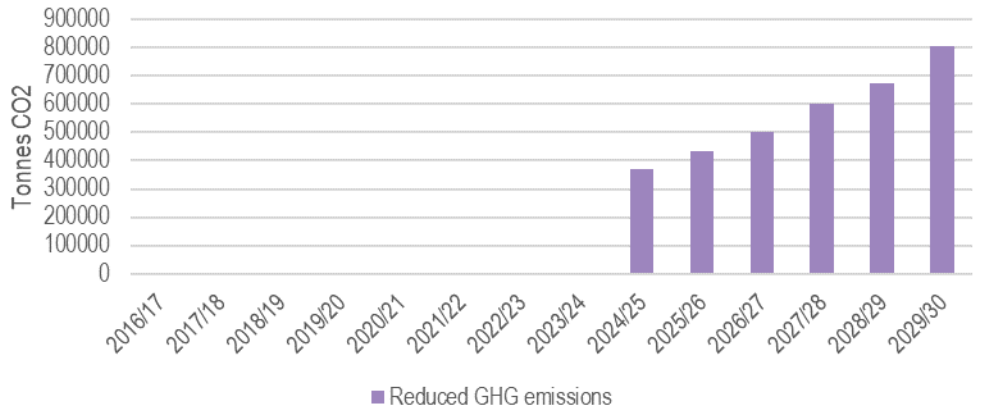
Other benefits reported by IMCRC project participants included reduced greenhouse gas (GHG) emissions, increased uptake in emerging technology, and the catalysing effect of the IMCRC. The figures discussed below have not been adjusted for attribution, and represent the total benefits achieved by the companies as a result of the project.

3.3.1 Environmental benefits

Over 3.38 million tonnes of CO_2 emissions are expected to be avoided over the analysis period as a result of the projects supported by the IMCRC, with all savings expected to occur in the future. Annual GHG emission reductions increase from approximately 370,845 tonnes of CO_2 in 2024-25 to over 800,000 tonnes of CO_2 in 2029-30.[20]

[20] Note that a small amount of GHG savings occurs in 2022-23 to 2023-24 (70 tonnes CO_2).

Figure 3.6 Reductions in GHG emissions (tonnes CO_2) (by year)



Source: ACIL Allen based on figures reported by IMCRC

For example, the Boral project was one of the projects that contributed to a reduction in GHG emissions. The Boral project has led to the development of a durable Lower Carbon Concrete (LCC) that reduces CO_2 emissions by 40 per cent compared to conventional concrete. This is achieved by substituting 70 per cent of the cement in the concrete with other materials. This is a significant achievement noting that cement production is the world's single biggest industrial cause of carbon pollution, responsible for 8 per cent of global emissions.[21]

There have also been environmental and sustainability benefits associated with the outcomes of some of the IMCRC's projects. For example, the technology developed by Lava Blue can be used to process what might otherwise be regarded as a waste stream from mining operations, which will help to reduce the amount of waste and also prevent the materials extracted from the waste from potentially entering the environment.

Similarly, the Monitum/Kurloo technology will enable better real time monitoring of tailings damns that contain mining waste, helping to ensure that their structural integrity is maintained and minimising the risks of any leakage or collapse that might cause environmental damage.

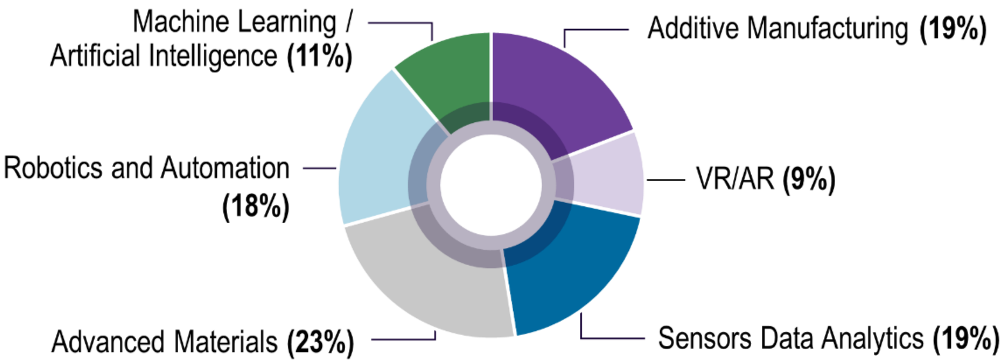
3.3.2 Uptake of emerging technologies

It is expected that there will be 181 cases where emerging technology will be adopted, trialled, or continue to be researched over the analysis period. Figure 3.7 below shows the breakdown of the uptake in emerging technology by type over the analysis period (2016-17 to 2029-30). The areas of technology that will be further addressed in this way include machine learning/artificial intelligence (11 per cent), robotics and automation (18 per cent), advanced materials (23 per cent), sensors and data analytics (19 per cent), virtual or augmented reality (9 per cent) and additive manufacturing/3D printing (19 per cent).

A majority of the uptake of technology occurred by 2021-22, with the rest expected to occur during 2022-23 and 2023-24.

[21] Beyond Zero Emissions, 2017, *Rethinking Cement*, available at: https://bze.org.au/wp-content/uploads/2020/12/rethinking-cement-bze-report-2017.pdf

Figure 3.7 Breakdown of uptake in technology by type over analysis period (2016-17 to 2029-30)



Source: ACIL Allen based on figures reported by IMCRC

Lava Blue reported that IMCRC funding facilitated the development of Lava Blue's machine learning models. These helped Lava Blue to understand how different impurities would affect the purification process and predict the outcome of their process. This has allowed Lava Blue to expand their potential feedstock from kaolin clay to a range of other feedstocks, including waste from tailing dams, and mineral biproducts from aluminium processes.

FormFlow in-phase corrugated corner

Source: FormFLow

ACIL Allen learnt from FormFlow that the design for its in-phase corrugated corner bend (pictured to the left) was first validated using 3D printed prototype tools. The new forming technology eliminates the need for pre roll formed corrugated sheet feed stock thereby reducing costs and improving product quality. The IP for the shape is now protected by a design registration.

3.3.3 Catalysing effect of the IMCRC

Another significant benefit of the IMCRC is the role it plays in catalysing additional developments and opportunities in the R&D sector. One example is IMCRC's role in helping to bring about the establishment of Stryker's Australian research and development (R&D) laboratory in Queensland (see Box 3.1). Stryker is an American multinational medical technologies corporation based in Michigan and had revenues of US$17.11 billion in 2021.[22]

[22] Refer: https://investors.stryker.com/press-releases/news-details/2022/Stryker-reports-2021-operating-results-and-2022-outlook/default.aspx

Box 3.1 Stryker opens R&D lab in Queensland

In September 2022, leading global medical technology company Stryker opened its Australian research and development (R&D) lab in Queensland. The lab, which is located in Brisbane's Herston Health Precinct alongside health facilities, medical research institutes, and universities, will focus on digital, robotics, enabling technology and advanced manufacturing research.

Stryker's investment in the R&D lab stems from its five-year, collaborative research project with IMCRC, RMIT University, St Vincent's Hospital, University of Technology Sydney, University of Sydney and University of Melbourne. The IMCRC project, which commenced in 2017, combined 3D printing, robotic surgery and advanced manufacturing to create patient-specific bone implants to treat bone cancers and tumours.

According to South Pacific President, Maurice Ben-Mayor, the IMCRC project really opened Stryker's eyes to what is possible in Australia.

> *Stryker's project with IMCRC demonstrated the importance of collaborative, open R&D and helped shape our current approach to innovation. We are delighted to take our next steps in Australia and support its future as a world leader in medtech with the opening of our R&D lab*

Maurice Ben-Taylor, 2022, IMCRC Media Release

Support for the lab has been provided by the Queensland government, University of Queensland, Queensland University of Technology and the Metro North Hospital and Health Service.

Source: IMCRC and AuManufacturing

In his remarks when officially opening the R&D lab, Stryker South Pacific President, Maurice Ben-Mayor, stated that:

> *Stryker's project with IMCRC demonstrated the importance of collaborative, open R&D and helped shape our current approach to innovation. We are delighted to take our next steps in Australia and support its future as a world leader in medtech with the opening of our R&D lab.*[23]

Maurice Ben-Mayor, Strykerr

Other examples of the IMCRC being a catalyst for broader investment in ongoing innovation include:

— The establishment of the Advanced Robotics for Manufacturing (ARM) Hub with IMCRC participants Urban Art Projects (UAP) and QUT in Brisbane, as a direct outcome from the UAP project

— The establishment of the BAE Systems Australia and Flinders University Line Zero facility at Tonsley in South Australia.

These examples illustrate the role that IMCRC has played in catalysing new facilities that build Australian design and manufacturing capability and capacity and that allow the IMCRC partners (and others) to continue to collaborate on research. ACIL Allen expects that these facilities will lead to further opportunities for researchers, universities, CSIRO and local industry. For example, we are aware of one researcher from the Stryker project that has since moved to work at the new R&D lab in Brisbane.

Planned future investment by project participants in the advanced manufacturing sector

The IMCRC have also reported a range of investments that project participants are planning as a result of the IMCRC. The types of investments planned, and the value of those investments are

[23] IMCRC media release, *IMCRC partner Stryker opens R&D Lab in Queensland*, 23 September 2022

presented in Table 3.4. The total amount of planned investment by industry partners over the period to 2029-30 is more than $2 billion.

Table 3.4 Investment by industry partners by type (2021-22 dollars)

Investment type	Description	Investment period	Expected investment amount
Planned Further R&D Investment	Further company research and development investment catalysed by IMCRC project	2020-21 to 2029-30	$186,328,338
Planned Future Capital Investment	Further company investment in facilities/infrastructure/capital equipment catalysed by IMCRC project	2021-22 to 2029-30	$310,514,917
Planned Future Workforce Development	Further company investment in workforce/staff/staff development planned catalysed by IMCRC project	2021-22 to 2029-30	$427,529,211
Planned Further Products/Parts Investment	Further investment in products and parts development catalysed by IMCRC project	2022-23 to 2029-30	$600,192,202
Planned Further Product Development	Further investment in product development/design/design for manufacture catalysed by IMCRC project	2021-22 to 2029-30	$363,298,777
Contracted manufacturing	Project outcomes resulted in contracted manufacturing or related services with other Australian businesses and service providers	2019-20 to 2029-30	$30,234,603.79
Third Party Investment in Business or Technology	IMCRC project resulted in additional third-party investments in business or technology including grants or private equity	2021-22 to 2029-30	$159,706,967
TOTAL			***$2,077,805,019***

Source: ACIL Allen based on IMCRC data

This significant planned future investment by industry partners as a result of the IMCRC shows IMCRC's impact on the investment in manufacturing and future growth in the sector.

3.4 Discussion

This chapter has explored the economic, social and other benefits that will occur from 2016-17 to 2029-30 as a result of the IMCRC's funding and investment model. The cost benefit analysis estimated economic benefits with a net present value of over $171.5 million, assuming a seven percent discount rate. The benefit-cost ratio (BCR) of the IMCRC's activities was estimated to be 1.8 at the same discount rate. Sensitivity testing was conducted and showed that the results of the CBA remained positive at a higher discount rate of 10 per cent, and also when a higher percentage for SG&A costs was used.

This chapter also explored other benefits that are expected to occur as a result of the IMCRC, which included employment opportunities, education and training, new businesses, increased collaboration and partnerships, reduced GHG emissions, and increased uptake of emerging technologies. This report has identified examples of these benefits from the IMCRC case studies. They demonstrate the real-world impacts of the benefits delivered as a result of the work done by the projects that were supported by the IMCRC.

While the work of the IMCRC is now largely concluded, the ongoing nature of many of these benefits in terms of further research and new businesses have been demonstrated by examples like Stryker's R&D lab in Brisbane, and the planned commercialisation of the technology developed by Lava Blue, Boral and others.

The Advanced Robotics for Manufacturing (ARM) Hub, and the BAE Systems Australia and Flinders University Line Zero facility at Tonsley in South Australia are two more examples of how the IMCRC has proved to be a catalyst for broader investment in ongoing innovation.

The significant planned future investment by industry partners as a result of the IMCRC also shows IMCRC's impact in driving additional investment in manufacturing and future growth in the sector.

The case studies 4

This chapter summarises the six case studies prepared as part of this project. Five of these are projects run by Australian owned SMEs. As such, the case studies are broadly representative of IMCRC's portfolio of industry partners and projects.

4.1 Case Study 1 - Lava Blue

In 2018 Lava Blue began working with QUT to develop processes at the laboratory level for refining High Purity Alumina (HPA) from the sapphire bearing kaolin clay deposits it owns at Lava Plains in North Queensland. HPA is a chemically inert ceramic material with high thermal and electrical resistivity. It is a critical component in the production of high technology products, such as LEDs, electronic displays; semiconductors; sapphire glass and separators for both lithium ion and aluminium batteries.

Having successfully produced HPA in a lab environment, Lava Blue needed to validate the process for making HPA from kaolin at the pilot and commercial level and sought and obtained support from the IMCRC to do this.

That funding allowed the project partners to develop a pilot plant that is able to process around 250 kg of kaolin clay feedstock to produce around 20 kg of HPA. The expected value add from that processing is considerable. The clay is valued at around $70 per tonne, whereas the HPA currently sells for around $25,000 per tonne.

The construction of the HPA pilot plant allowed the project team to reduce the technical risks associated with scaling up HPA production to a commercial scale. The project team used in-line monitoring, real time process control and machine learning to develop improved process control. This allowed the project team to carry out multiple tests of the chemical processes in parallel rather than only being able to vary one element of the process at a time.

It also enabled the team to develop advanced control systems that will result in a reliable supply of a high-purity product that meets the stringent quality requirements of users. The researchers have also said that there is potential for the results of the project to be extended to processes for extracting other minerals from ores as well as from waste material.

Queensland Pacific Metals (QPM) has entered into a licence agreement with Lava Blue to use their proprietary HPA technology in their Townsville Energy Chemicals Hub (TECH) Project. QPM Managing Director, Dr Stephen Grocott, stated that:

> *From our Pre-Feasibility Study, it was evident that HPA production is a significant value enhancer for the TECH Project. We are delighted to work with Lava Blue and their partners QUT and Engenium. This joint development significantly advances us with respect to achieving commercial production of HPA at the TECH Project.*
>
> *Dr Stephen Grocott, QPM*

QPM's HPA plant is expected to have the capacity to produce around 4,000 tonnes of HPA per year with an estimated market value of around $100 million.

Table 4.1 shows the results of the Cost Benefit Analysis (CBA) of the project using 3, 7 and 10 per cent discount rates.

Table 4.1 NPV of economic impacts of the Lava Blue project at the 3, 7, and 10 per cent discount rate (2021-22 dollars)

	Discount rate 3%	Discount rate 7%	Discount rate 10%
Costs	$11,216,296	$11,525,413	$11,762,583
Benefits	$18,282,323	$14,924,956	$12,938,340
Net present value	**$7,066,028**	**$3,399,543**	**$1,175,757**
BCR	**1.63**	**1.29**	**1.10**

Note: Note that the benefits reported by Lava Blue have been adjusted to consider the attribution of benefits to IMCRC. The analysis period was from 2016-17 to 2029-30

Source: Data provided by IMCRC

4.2 Case Study 2 – Boral

Boral worked with the University of Technology Sydney (UTS) to expand its Lower Carbon Concrete (LCC) range. LCC products reduce CO_2 by supplementing some Ordinary Portland Cement (OPC) with cementitious materials (SCMs). OPC is the main binder for concrete and is also the second biggest contributor to carbon emissions after fossil fuels. Boral has already successfully commercialised a range of LCC products, with some products replacing up to 50 per cent of OPC content with SCMs. .[24] The focus of this project was to seek to expand Boral's LCC range to include a concrete that replaces 70 per cent of OPC with SCMs, while retaining the strength and durability properties required by their customers.

The IMCRC project, which commenced in late 2020, was the first major project at the newly established UTS Boral Centre for Sustainable Building at UTS Tech Lab, within the School of Civil and Environmental Engineering. At the UTS Tech Lab, UTS and Boral examined the effectiveness of the proposed manufacturing approaches for the 70 per cent SCM concrete and tested methods to improve the concrete's surface finishing techniques. This involved looking at the strength and mechanical properties of the concrete and conducting a broad range of tests to achieve the required performance. The UTS Faculty of Design, Architecture & Building worked with Boral to evaluate the life cycle analysis and life cycle cost of the new lower carbon concrete, highlighting the benefit to both the environment and cost in buildings and infrastructure.

Boral also worked closely with the UTS Business School during this project. The UTS Business school conducted a marketing study to analyse the target market for Boral's LCC and the potential take-up of the product in the construction sector.

These activities, which were supported by IMCRC funding, led to the development of a 70 per cent SCM concrete product that is ready to go to market. The product's internal specifications have been fully documented. The concrete performs as well as, if not better than, conventional concrete in terms of strength and its ability to be pumped. The LCC concrete is expected to be similar in cost to regular concrete.

Not only is the commercialisation of this concrete expected to lead to significant economic impacts, but it is also expected to result in significant emissions savings for Boral and its customers. Almost

[24] Refer: https://www.sciencedirect.com/science/article/abs/pii/S095965261600158X

30 million cubic metres of concrete are used in Australia every year, with regular concrete producing as much as 350 kg CO_2/cubic metre of carbon emissions.

Boral's 70 per cent SCM concrete has already been trialled in two major projects.

Although Boral and UTS had an existing relationship prior to this project, Ali Nezhad (GM Innovation, Boral) and Jason Chandler (Head of Innovation R&D, Boral-UTS Tech Lab) stated that the IMCRC project strengthened the UTS-Boral partnership significantly:

> *From an industry and university collaboration point of view, IMCRC extended the partnership beyond the scope initially imagined. That extended partnership is continuing today*
>
> *Ali Nezhad, Boral*

Not only did it strengthen the collaboration between Boral and the School of Civil and Environmental Engineering, but also with the UTS Business School, which is continuing in other Boral projects. As a result of the IMCRC project, Boral is developing a model to improve collaboration with the university sector.

Economic benefits of the Boral project were estimated through a cost-benefit analysis at the 3, 7 and 10 per cent discount rates over the analysis period (2016-17 to 2029-30). Although the figures cannot be reported due to commercial sensitivities, ACIL Allen found that the net present value was positive, and the benefit-cost ratio was above one at all three discount rates.

4.3 Case Study 3 - FormFlow

This IMCRC project focused on improving the process of manufacturing FormFlow's foundation technology, the C90 bend, which was patented by FormFlow in 2016. It was a world first innovation that enabled the formation of a 90-degree bend in corrugated sheets without damaging the material's structure or coating. The technology forms a continuous corner that allows seamless joins between walls and roofing.

IMCRC funding helped FormFlow to purchase equipment and hire the expertise needed to improve the product quality of inputs as well as the repeatability of FormFlow's bend. The outputs of the project were:

— A 2D laser system that enables the manufacturer to perform continuous, real-time quality control. The 2D profile scanner combines a high-resolution laser with evaluation software to monitor the shape of building materials before and after they are manufactured into FormFlow products or integrated into FormFlow's building systems.

— A new forming technology capable of producing a corrugated corner bend from a flat sheet of steel. This eliminates the need for pre-roll formed corrugated sheet feed stock, which reduces costs and improves product quality.

The IMCRC project, which ran for 12 months, commenced in November 2020. FormFlow purchased hardware for the laser system, installed a sheet bending press and developed the first prototype of the forming technology with the funding from IMCRC. A part-time RMIT student was also hired to develop the program for the laser system. FormFlow reported that they collaborated with a wide range of groups during the project, including staff from the local engineering firm Austeng, flat product steel producer BlueScope (who owns Lysaght) and the School of Architecture, Construction Management and Civil Engineering at Deakin University.

IMCRC's adaptability during the IMCRC project supported changes in FormFlow's processes which led to new discoveries and opportunities — for example, the development of new modular building systems to deliver high quality, affordable housing rapidly and at high volumes. The company has used their technologies to deliver a range of housing solutions to address, amongst other things, bushfire resilience, and rapid response disaster relief housing.

One example is the FormFlow Veranda Fire House, which was created in collaboration with Ian Weir, one of the country's leading architects in the design of Australian bushfire-safe homes. The Veranda Fire House features the FormFlow C90 bend to create a 'no gaps' barrier against ember attacks and extreme heat and can be configured in multiple ways including as a commercial building or a bushfire proof residential home.

When asked about the role of IMCRC, Dr Mattias Weiss, FormFlow's university partner from Deakin University, stated that:

> *We weren't able to control the [steel] shapes easily, so we did a complete U-turn and developed a new process which proved to be a great success. That turnaround would not have been possible without the IMCRC funding, which allowed us to install a [hydraulic] press and develop the first prototype of the new process.*
>
> *Dr Mattias Weiss, Deakin University*

Table 4.2 shows the results of the Cost Benefit Analysis (CBA) of the project when using 3, 7 and 10 per cent discount rates.

Table 4.2 NPV of economic impacts of the FormFlow project at the 3, 7, and 10 per cent discount rate (2021-22 dollars)

	Discount rate 3%	Discount rate 7%	Discount rate 10%
Costs	$611,306	$624,978	$635,232
Benefits	$16,171,670	$13,192,536	$11,413,710
Net Present Value	**$15,560,364**	**$12,567,559**	**$10,778,478**
BCR	**26.45**	**21.11**	**17.97**

[a] Note that the benefits reported by FormFlow have been adjusted to consider the attribution of benefits to IMCRC, as well as expected costs relating to selling, general and administrative expenses. The analysis period was from 2016-17 to 2029-30

Source: Data provided by IMCRC

4.4 Case Study 4 - Monitum/Kurloo Movement Detector System

In 2018, Monitum partnered with the Queensland University of Technology (QUT) to develop a cost-effective Internet of Things (IoT) solution using low-medium-end Global Navigation Satellite System (GNSS) sensors and low-power wide-area networks.

Working with QUT, Monitum has created a fully integrated smart device that is supported by a cloud processing and data analytics service. Together, they enable millimetre-precise deformation data to be obtained automatically, remotely and in near real-time.

To overcome a gap between IoT sensor and standalone GNSS technology in the market, a four-level IoT reference framework (sensors, networks, service platform and applications) was established to simplify the development, deployment, service and upgrade of each GNSS IoT component. The new GNSS-IoT system has allowed Monitum to develop a new business model that automates the monitoring of structures, reducing the risk and cost in the construction and maintenance of infrastructure assets.

This project involved partnerships with Australian manufacturing companies and service providers. Two prototypes were developed during the project and tested as Minimum Viable Product to establish software and application programming interface. Monitum installed and tested the sensor devices across multiple environments including large scale infrastructure for the likes of Port of Brisbane and Queensland Rail.

Monitum launched its new technology through its spin-off company, Kurloo in June 2022. The products and services that it provides will; save customers time and money. It also reduces risks and improves safety.

IMCRC provided funding and advice, helping to commercialise the product. IMCRC helped the project to identify a manufacturer. IMCRC incentivised university-industry collaboration and drove co-investment.

> *By championing the project and being a hands-on advisor, IMCRC helped formalise our idea, kept us committed to the innovation, and ensured we were able to reach mutually beneficial outcomes. This enabled us to engage a local Australian manufacturer, giving greater design control and certainty of a local supply chain.*
>
> *Lee Hellen, Managing Director*

In the near term, the market for the product and services arising from this project are estimated to be 500 units by the end of 2022-23 and four to five thousand units a year in the near future. Table 4.2 shows the results of the Cost benefit Analysis (CBA) of the project, using 3, 7 and 10 per cent discount rates.

Table 4.2 NPV of economic impacts of the Monitum project at the 3, 7, and 10 per cent discount rate (2021-22 dollars)

	Discount rate 3%	Discount rate 7%	Discount rate 10%
Costs	$4,949,759	$5,053,278	$5,134,604
Benefits	$46,433,210	$39,206,136	$34,731,594
Net Present Value	**$41,483,451**	**$34,152,858**	**$29,596,989**
BCR	**9.38**	**7.76**	**6.76**

Note that the benefits reported by Monitum have been adjusted to consider the attribution of benefits to IMCRC, as well as expected costs relating to selling, general and administrative expenses. The analysis period was from 2016-17 to 2029-30
Source: data provided to IMCRC

4.5 Case Study 5 - Codex Bioreactor

Codex Research (Codex) CEO Ed Brackenreg and Associate Prof Steven Wise saw the limitations of laboratory cell assays as a challenge that needed addressing. For example, vascular cells have been grown in flat plastic dishes, which is far removed from their environment in humans. Developing a bioreactor that closely simulated a human system would be a major advance.

Codex, in collaboration with Sydney University since 2018, has developed a device called a bioreactor which grows patient-derived cells in a dynamic environment that closely mimics that of living human tissues. The bioreactor, which is now at advanced prototype stage, provides a much better environment for studying medical problems, without having to use animal models. This has been made possible because of the partnership between Codex Research CEO Ed Brackenreg and the Associate Professor Wise's team at Sydney University.

> *There's no way we could possibly have made this progress alone, in-house, without partnering with experts working in a well-equipped lab, producing scientifically credible outcomes that then convince other funding bodies that the project is worth supporting through further development.*
>
> *Ed Brackenreg, Codex*

While at first optimised for the development of tissue engineered vascular grafts, the bioreactor will serve as a base technology upon which different applications can be built. This will allow Codex Research to access clinical, regenerative medicine, and medical science research markets.

In the near term the market for the bioreactor is expected to be for research. The number of research groups around the world that might wish to purchase the bioreactor is quite large. In the medium term, the bioreactor has clinical applications in cardiology. The longer-term market depends on the outcome of further research and development using the bioreactor in applications ranging from organ transplants to cancer.

At a discount rate of 7 per cent, the Net Present Value (NPV) is expected to be $15,674,675 over the analysis period (2016-17 to 2029-30), and the BCR is 3.23.

Table 2 NPV of economic impacts of the Codex project at the 3, 7, and 10 per cent discount rate (2021-22 dollars)

	Discount rate 3%	Discount rate 7%	Discount rate 10%
Costs	$6,461,441	$6,670,129	$6,834,974
Benefits	$28,568,331	$22,344,803	$18,726,716
Net Present Value	**$22,106,890**	**$15,674,675**	**$11,891,742**
BCR	**4.42**	**3.35**	**2.74**

Note that the benefits reported by Codex have been adjusted to consider the attribution of benefits to IMCRC, as well as expected costs relating to selling, general and administrative expenses. The analysis period was from 2016-17 to 2029-30
Source: data provided by Codex to IMCRC

4.6 Case Study 6 - Whiteley Corporation

Up to 80 per cent of human bacterial infections are biofilm associated. Biofilms formed by bacteria can attach to living and non-living surfaces, such as implants and medical devices such as catheters, where they pose a significant infection risk for patients. Whiteley Corporation (Whiteley) has worked with Associate Professor Jim Manos of Sydney University and researchers at the University of NSW to develop ways to address this problem.

This project has taken a new approach to resolving bacterial biofilm problems in humans and industrial settings, through mimicking natural, synergistic multimodal strategies. Whiteley together with the University of Sydney has developed several new therapeutic treatments for biofilm mediated infection, that effectively disrupt the formation of biofilm and eradicate underlying bacteria found, for instance, in the lungs of cystic fibrosis patients, chronic urinary tract infections and burn wounds.

Using advanced manufacturing design methods combined with Industry 4.0 manufacturing processes, the project has developed and manufactured small, highly customisable high-value products in a Good Manufacturing Product (GMP) environment, including novel packing and a dosage delivery device.

The project has resulted in the development of number of multi-modal formulations for biofilm disruption for infections including diabetic leg wounds, urinary tract infections and infections impacting people with cystic fibrosis. As a result of the research and testing of new formulations, manufacturing processes have been developed for commercial production under GMP conditions.

The first product from this project, to remove biofilms from equipment used in dental surgeries, was launched in October 2022. A further product is scheduled to be launched in mid-2023.

At a discount rate of 7 per cent, the Net Present Value (NPV) is expected to be $7,205,057 over the analysis period (2016-17 to 2029-30), and the BCR is 2.16.

Table 2 NPV of economic impacts at the 3, 7, and 10 per cent discount rate (2021-22 dollars)

	Discount rate 3%	Discount rate 7%	Discount rate 10%
Costs	$5,914,233	$6,233,042	$6,485,064
Benefits	$16,848,354	$13,438,098	$11,434,691
Net Present Value	**$10,934,122**	**$7,205,057**	**$4,949,627**
BCR	**2.85**	**2.16**	**1.76**

Note that the benefits reported by Whiteley have been adjusted to consider the attribution of benefits to IMCRC, as well as expected costs relating to selling, general and administrative expenses. The analysis period was from 2016-17 to 2029-30
Source: data provided by Whiteley to IMCRC

4.7 Discussion of the Case Studies

ACIL Allen has developed six case studies that examine six of the projects supported by the IMCRC in more detail. Each case study includes a CBA based on the information that the project teams provided to the IMCRC.

Table 4.3 provides a summary of the results of the analysis done by ACIL Allen. The table provides the estimated NPV and the BCR (when using a discount rate of 7 per cent) for each of the projects that have been used as case studies. As can be seen, all the NPVs are positive and the BCRs are all above one (some significantly).

Table 4.3 Summary of CBA analysis (with a 7 per cent discount rate)

Case study	Net Present Value	BCR
Lava Blue	$3,399,543	1.29
FormFlow	$12,567,559	21.11
Monitum (Kurloo)	$34,152,858	7.76
Codex Bioreactor	$15,674,675	3.35
Whiteley Corporation	$7,205,057	2.16
All 5 case studies	**$72,999,691**	**3.42**

Source: ACIL Allen analysis of data from IMCRC
Note that these figures exclude the results of the economic analysis of the Boral project due to its commercial sensitivity.

Table 4.3 also shows that the sum of the net present values of the six projects used to develop the case studies is over $83 million. This is more than twice the total amount invested by IMCRC to support all its R&D projects. The BCR for all six case studies is 2.98. This means that every dollar invested by IMCRC and the partners in these six projects returned almost three dollars in benefits.

As has already been noted several times above, ACIL Allen believes that the benefits associated with the six case studies we have developed represent a robust lower bound of the benefits that will ultimately result from these projects. However, we anticipate that the eventual benefits of these six projects are likely to be significantly higher than the estimates presented in this report.

Conclusions 5

5.1 Impact of IMCRC

The primary question this study sought to answer is what the 'returns' are from the funds that the IMCRC has invested in the projects it has supported. The results of our cost benefit analysis of the IMCRC's entire portfolio of projects and of the projects selected as case studies are shown in Table 5.1. The analysis found that the estimated BCR for the IMCRC as a whole was 1.8. In other words, every dollar invested in the projects supported by the IMCRC generated, on average, a benefit of $1.80.

Table 5.1 Estimated NPVs and BCRs for the IMCRC (7 per cent discount rate)

Case study	Estimated NPV	BCR
Lava Blue	$3,399,543	1.29
FormFlow	$12,567,559	21.11
Monitum (Kurloo)	$34,152,858	7.76
Codex Bioreactor	$15,674,675	3.35
Whiteley Corporation	$7,205,057	2.16
All 5 case studies	$72,999,691	3.42
All IMCRC projects	**$171,490,402**	**1.8**

Source: ACIL Allen

Note that these figures exclude the results of the economic analysis of the Boral project due to its commercial sensitivity.

The results show that the six case studies delivered quantifiable benefits well in excess of their costs. The same is true of the IMCRC as a whole. As noted previously, there have been additional social and environmental benefits that have not been able to be quantified. In addition, while benefits have been projected to 2029-30, all of the case study projects and most of the other IMCRC projects, are expected to continue to generate benefits past that year. ACIL Allen believes that achieving this level of 'return on investment' from R&D projects is a very good result. Many of the projects supported by IMCRC are only just completed and it is likely to take some time before those that have developed an innovative technology or process can be commercialised. The Lava Blue case study found that there is already one licencing agreement in place to build a plant based on Lava Blue IP. ACIL Allen estimates that if that plant was built, it alone would manufacture a product that could generate export revenue of around $100 million a year (we understand that two additional licencing agreements are being negotiated).

We note that the BCR would be significantly higher if analysis was performed from the perspective of the businesses that participated in the IMCRC, rather than using a CBA approach which considers costs and benefits from a societal perspective. From the perspective of the businesses that participated in the CRC, their investment was roughly $108 million ($35 million in cash and $73 million in-kind) and the benefits they received were almost $4.2 billion (2021-22 dollars).

The IMCRC is coming to the end of its funding period. As part of this impact evaluation study the IMCRC has asked ACIL Allen to answer the evaluation questions in Table 5.2. The table also includes three additional questions that the Commonwealth's required post CRC completion Evaluation Report are required to address.

5.2 Impact of IMCRC and looking forward

The results of the CBA, the analysis of social and other benefits, as well as the strong testimonies within the case studies show that the industry-led model of the IMCRC has resulted in significant positive impacts for the Australian manufacturing industry. There is also evidence that this model has resulted in a shift in culture towards stronger industry and research collaboration for project participants.

The fact that industry has reported ongoing benefits from the IMCRC out to 2029-30 also shows the ongoing nature of these impacts. Data from industry partners as well as discussions with industry suggest that project participants will continue to invest in R&D, hire staff (including from the research sector), experiment with emerging technology, enter new collaborations and partnerships, and see significant returns into the future

Table 5.2 Evaluation and end of Commonwealth grant questions and responses

Question	Answer	Comment
Evaluation questions		
1. What is the Government's and Industry's return on investment for IMCRC?	The best-practice cost benefit analysis, which examined the value of IMCRC from a societal perspective, found that the NPV of the IMCRC was $172m (2021-22 dollars, 7%DR, BCR of 1.8). When the benefits are examined from a government and business perspective (not a formal CBA approach) it can be concluded that: — Through the IMCRC, the Government invested $35 million which generated estimated benefits of almost $4.2 billion for industry (2021-22 dollars). — Industry invested $108 million and received benefits worth almost $4.2 billion (2021-22 dollars).	See chapter 3 for discussion on the cost-benefit analysis.
2. Is IMCRC achieving its intended outcomes? What is the magnitude of the changes that occurred?	The IMCRC has achieved its intended outcomes. The changes in the 71 firms that it supported are impressive. Additional revenues from IMCRC-funded projects are expected to exceed $3.7 billion up to the end of 2029-30 (2021-22 dollars). Other benefits over 2016-17 to 2029-30 include: — 6,089 ongoing FTE by 2029-30 — 45 postgraduate completions — 224 collaborations and partnerships — 22 new businesses and business opportunities — 181 cases of industry partners trialling and adopting new technology over 2016-17 to 2029-30. Areas of investment include machine learning/artificial intelligence, robotics and automation, advanced materials, sensors and data analytics, virtual or augmented reality, and additive manufacturing/3D printing. — Over $2 billion of future R&D investment planned by industry partners — 750 businesses involved in futuremap™ workshops, which showcased IMCRC's business maturity diagnostic tool	See discussion on other benefits in Chapter 2 and Chapter 3.
3. To what extent has IMCRC increased the strength and quality of business-research collaboration in Australia?	IMCRC-assisted firms report having achieved significant improvements in the strength and quality of their business-research collaborations, as is demonstrated in the case studies. For example, Boral stated that collaboration with UTS was significantly strengthened through the IMCRC projects. IMCRC catalysed 224 further collaborations and partnerships for industry partners, (including international collaborations) over 2029-30	See chapter 4 for case study summaries, and Appendix C through H for full case studies. See section 3.2.4.for collaboration and partnership analysis.

Question	Answer	Comment
4. To what extent has IMCRC generated a culture of industry-research collaboration, with firms and researchers seeing value in collaborative partnerships?	The fact that many IMCRC-supported collaborations are continuing beyond the end of their funding by IMCRC suggest that there has been a step change in the culture of industry-research collaboration. This is demonstrated in the case studies.	See chapter 4 for case study summaries, and Appendix C through H for full case studies. See section 3.2.4.for collaboration and partnership analysis.
5. To what extent has IMCRC contributed to the competitiveness, sustainability and productivity of Australian manufacturing and supported commercial outcomes?	The cost benefit analysis has a strong NPV of $172m and BCR of 1.8 which shows the significant productivity benefits of the IMCRC to the Australian economy through its support of the manufacturing sector. A reduction of over 3.48 million tonnes of CO_2 emissions are estimated by industry partners over the analysis period as a result of the IMCRC's support. Further, encouraging and assisting the uptake of Industry 4.0 approaches will enhance competitiveness and increase productivity.	See chapter 3
6. Has IMCRC improved commercialisation and business performance?	The commercialisation achievements of IMCRC-supported firms and the improvements in their business performance are reflected in the figures reported back to IMCRC. These include benefits out to 2029-30, in 2021-22 dollars such as: — Cost Savings of $333,486,313 — Cost Avoidance $18,922,888 — Additional Revenue $3,785,796,479 — Customer Savings and Efficiencies $57,844,627 As well as other benefits shown in the answer to question 2 above.	See chapter 3
7. To what extent has IMCRC increased research training and improved the capability of the manufacturing research workforce?	IMCRC projects have involved 45 students receiving research training and the case studies suggest that many have, or are expected to take up employment opportunities in industry.	See 3.2.3 on education and training.
8. What are the intended and unintended outcomes achieved IMCRC relevant to the Government's strategic priorities?	The support provided by the IMCRC has been well aligned with Government strategic priorities. Over two thirds of the funding provided by the IMCRC was for projects that were in the sectors that had been identified as National Manufacturing Priorities. This has led to strong outcomes in the priority areas.	See section 2.7.2 on the alignment of IMCRC projects with National Manufacturing Priorities.
9. Are the IMCRC outcomes achieved to date in line with the Government's current and forward priorities?	In addition to the response to Q8 above, in 2022 the Australian Government identified the following sectors as being key ones for the nation:	See section 2.7.2 on IMCRC's alignment with national priorities

Question	Answer	Comment
	– Defence – Enabling capabilities – Transport – Medical sciences – Resources – Renewables and low emission technologies The IMCRC projects align closely with these key areas (see section 2.7.2) The six industry sectors supported by the Australian Government Industry Growth Centre Initiative (IGCI) are also well-addressed by the IMCRC projects (see section 2.7.2). The six sectors are: – Advanced Manufacturing (known as the Advanced Manufacturing Growth Centre (AMGC)) – Cyber Security (known as AustCyber) – Food and Agribusiness (known as Food Innovation Australia Limited (FIAL)) – Medical Technologies and Pharmaceuticals (known as MTPConnect) – Mining Equipment, Technology and Services (known as METS Ignited) – Oil, Gas and Energy Resources (known as National Energy Resources Australia (NERA)).	
10. How well do IMCRC's participants match the intended target group and is the reach sufficient to realise the required scale of change?	The IMCRC has targeted SMEs, supporting firms across Australia. Eighty per cent of the industry participants in the projects were SMEs and almost a quarter of these were regional firms. The substantial number of firms that have participated in Futuremap workshops is a further indication of the reach of the IMCRC. With further effort following the practices of the IMCRC, the reach of this successful CRC can be extended.	See section 2.7.1
11. What are the main factors contributing to the outcomes?	One of the main factors contributing to the outcomes achieved is the industry-led approach adopted by the IMCRC. The selection and operational processes used by the IMCRC have played an important role. This is evident through the testimonies provided in the case studies. Estimated additional revenue of almost $3.8 billion over 2016-17 to 2029-30 was the largest benefit to participants.	See chapter 4 for case study summaries, and Appendix C through H for full case studies. See 3.1.1 for CBA summary.
12. How much does IMCRC's outcomes contribute to economic growth (GDP), real consumption, real investment and taxation revenue?	There will be flow on benefits to the Australian economy, including tax revenues, from these outcomes. These could be quantified through Computable General Equilibrium (CGE) modelling.	

Question	Answer	Comment
13. What, if any, lessons can be drawn from IMCRC to improve the efficiency or effectiveness of future manufacturing research initiatives or programs?	More of this approach to creating value in the manufacturing sector will generate significant benefits. ACIL Allen also heard from case study subjects that IMCRC's model and approach to projects improved efficiency and focus of research outcomes. The IMCRC model increased collaboration between industry and universities which led to significant value, learning opportunities, and strengthened scientific understanding, which led to better project results. Research partners noted that the IMCRC's strong project management approach kept researchers focused and led to efficiency gains in terms of outcome delivery.	See chapter 4 for case study summaries, and Appendix C through H for full case studies.
End of CRC Evaluation Report Questions (Commonwealth requirement)		
1. What is the level of satisfaction from those who participated in the CRC and examples of benefits they received and value from their involvement	The industry and research participants in the six case studies all without exception spoke highly of the CRC and the support that it had provided to their projects. The case studies identified many examples where the IMCRC had helped the project participants. This included putting them in touch with other firms that could bring required skills to the project and organisations that could support their business planning.	See discussion of case studies in Chapter 4. A more complete assessment of the levels of satisfaction would require a specific survey to be conducted.
2. How well has collaboration improved competitiveness and productivity, including beyond the end of the CRC?	The IMCRC funding is now complete. At this time, the prospects for ongoing collaboration, productivity gains and increased competitiveness for the firms that have been impacted by the IMCRC look very strong. Benefits out to 2029-30 reported by industry include: cost savings of $334m; cost avoidance $19m; additional revenue of $3.8b; savings and efficiencies for industry of $58m; 6,089 ongoing FTE by 2029-30; 45 postgraduate completions; 224 collaborations and partnerships; 22 new businesses and business opportunities; Over $2b of future R&D investment planned by industry partners; 750 businesses involved in futuremap™ workshops, which showcased IMCRC's business maturity diagnostic tool. Industry also reported 181 cases of trialling and adopting new technology over 2016-17 to 2029-30. Areas of investment include machine learning/artificial intelligence, robotics and automation, advanced materials, sensors and data analytics, virtual or augmented reality, and additive manufacturing/3D printing	
3. What unintended benefits resulted from the CRC?	Another significant (and potentially unintended) benefit of the IMCRC is the role it played in catalysing additional developments and opportunities in the R&D sector. For example, the establishment of Stryker's Australian research and development (R&D) laboratory in Queensland.	See discussion in section 3.3.3.

Source: ACIL Allen

Appendices

IMCRC manufacturing readiness levels (MRL)

A

The MRL matrix presented below has been utilised by IMCRC for project applications, project management and reporting.

LEVEL	MRL 1	MRL 2	MRL 3	MRL 4	MRL 5	MRL 6	MRL 7	MRL 8	MRL 9	MRL 10
Phase	Technology assessment and initial proving				Technology development and pre-production		Engineering and Manufacturing development		Production and deployment	Operations and support
IMCRC Project Research focus	Not core focus level	Influencing role		Primary IMCRC Project Research focus				Influencing role	Not core focus level	
Industrial Transformation focus	Not core focus level				Influencing role		Primary Industrial Transformation focus			
Definition	Basic manufacturing implications identified	Manufacturing concepts identified	Manufacturing proof of concept developed	Capability to produce the technology in a laboratory environment.	Capability to produce prototype components in a production relevant environment.	Capability to produce a prototype system or subsystem in a production relevant environment.	Capability to produce systems, subsystems or components in a production representative environment.	Pilot line capability demonstrated. Ready to begin low rate production.	Low Rate Production demonstrated. Capability in place to begin Full Rate Production.	Full Rate Production demonstrated and lean / six sigma production practices in place.
Description, Outputs and Outcomes	Basic research expands scientific principles that may have manufacturing implications. The focus is on a high level assessment of manufacturing opportunities. The research is not confined or restricted.	Invention begins. Manufacturing science and/or concept described in application context. Identification of material and process approaches are limited to paper studies and analysis. Initial manufacturing feasibility and issues are emerging.	Conduct analytical or laboratory experiments to validate paper studies. Experimental hardware or processes have been created, but are not yet integrated or representative. Materials and/or processes have been characterized for manufacturability and availability but further evaluation and demonstration is required.	Required investments, such as manufacturing technology development identified. Processes to ensure manufacturability, producibility and quality are in place and are sufficient to produce technology demonstrators. Manufacturing risks identified for prototype build. Manufacturing cost drivers identified. IP Utilisation plan developed. Producibility assessments of design concepts have been completed. Key design performance parameters identified. Special needs identified for tooling, facilities, material handling and skills.	Manufacturing strategy refined and integrated with Risk Management Plan. Identification of enabling/critical technologies and components is complete. Prototype materials, tooling and test equipment, as well as personnel skills, have been demonstrated on components in a production relevant environment, but many manufacturing processes and procedures are still in development. Manufacturing technology development efforts initiated or ongoing. Producibility assessments of key technologies and components ongoing. Cost model based upon detailed end-to-end value stream map.	Initial manufacturing approach developed. Majority of manufacturing processes have been defined and characterized, but there are still significant engineering/design changes. Preliminary design of critical components completed. Producibility assessments of key technologies complete. Prototype materials, tooling and test equipment, as well as personnel skills have been demonstrated on subsystems/ systems in a production relevant environment. Detailed cost analysis include design trades. Cost targets allocated. Producibility considerations shape system development plans.	Detailed design is underway. Material specifications are approved. Materials available to meet planned pilot line build schedule. Manufacturing processes and procedures demonstrated in a production representative environment. Detailed producibility trade studies and risk assessments underway. Cost models updated with detailed designs, rolled up to system level and tracked against targets. Unit cost reduction efforts underway. Supply chain and supplier Quality Assurance assessed. Long lead procurement plans in place. Production tooling and test equipment design	Detailed system design essentially complete and sufficiently stable to enter low rate production. All materials are available to meet planned low rate production schedule. Manufacturing and quality processes and procedures proven in a pilot line environment, under control and ready for low rate production. Known producibility risks pose no significant risk for low rate production. Engineering cost model driven by detailed design and validated. Supply chain established and stable.	Major system design features are stable and proven in test and evaluation. Materials are available to meet planned rate production schedules. Manufacturing processes and procedures are established and controlled to three-sigma or some other appropriate quality level to meet design key characteristic tolerances in a low rate production environment. Production risk monitoring ongoing. Low Rate Initial Produciton (LRIP) cost goals met, learning curve validated. Actual cost model developed for Full Rate Production environment, with impact of Continuous improvement.	This is the highest level of production readiness. Engineering/design changes are few and generally limited to quality and cost improvements. System, components or items are in rate production and meet all engineering, performance, quality and reliability requirements. All materials, manufacturing processes and procedures, inspection and test equipment are in production and controlled to six-sigma or some other appropriate quality level. Full Rate Production unit cost meets goal, and funding is sufficient for production at required rates. Lean practices well
Complementary Technology Readiness Level	TRL 1	TRL 2	TRL 3	TRL 4	TRL 5	TRL 6	TRL 7	TRL 8	TRL 9	
	Basic research. Principles postulated and observed but no experimental proof available.	Technology formulation. Concept and application have been formulated.	Applied research. First laboratory tests completed; proof of concept.	Small scale prototype build in laboratory environment ("rough and ready" prototype).	Large scale prototype tested in intended environment.	Prototype system tested in intended environment close to expected performance.	Demonstrated system operating in operational environment at pre-commercial scale.	First of a kind commercial system. Manufacturing issues solved.	Full commercial application, technology available for consumers.	

CBA reference case, counterfactual and assumptions

B

This appendix describes the reference case and counterfactual of the IMCRC Cost-benefit-Analysis (CBA), as well as assumptions around the benefits.

The counterfactual acts as the baseline of the CBA. That is, for benefits of the reference case to be counted, they must be additional to the counterfactual scenario. For example, if an IMCRC project brings about the same result that would have happened regardless of the IMCRC's involvement, it cannot be counted towards the benefits of the CBA. However, if the project resulted in better results due to IMCRC's involvement, then those additional benefits can be counted towards the CBA.

Counterfactual (scenario with no IMCRC)

The Counterfactual is used as a baseline to which the benefits generated by the IMCRC can be compared. Under this scenario it is assumed that:

IMCRC was not established. The IMCRC projects go ahead without IMCRC funding and guidance.

The implications of this will vary from project to project. For some projects it may mean that the project would have taken a longer period of time to achieve the same outcome, for others it may mean that the outcome is significantly worse compared to the scenario where IMCRC is involved, or the project may not have happened at all (note that benefits under the reference case have been appropriately adjusted for IMCRC attribution).

We have heard some anecdotal evidence of what may have happened in the absence of IMCRC funding:

We have heard from stakeholders that IMCRC funding have allowed for superior processes (e.g. AI machine learning processes rather than manual/trial-and-error processes) to be developed. These processes would not have been developed without IMCRC because it would not have been possible to recruit the breadth of expertise needed with industry funding alone.

We have also heard from some industry stakeholders that the IMCRC model has shown industry the value of collaborating with university, so this model is something they would take forward in future. Furthermore, IMCRC have provided insights and connections to industry that have allowed industry to find resolutions and viable research pathways more quickly.

Reference case (IMCRC scenario)

The reference case describes present day i.e. the current scenario with IMCRC providing guidance and financial support for innovative manufacturing collaborations between industry and universities.

Assumptions around benefits (and definitions)

All benefits have been adjusted by IMCRC for attribution

Note that some outlier figures have been interrogated and attribution has been further reduced.

The full list of benefits that were provided to ACIL Allen by IMCRC was interrogated and the following list has been chosen for inclusion in the CBA:

Cost avoidance: The value of costs avoided through research conducted under the IMCRC Project

For example, we have heard that some participants did not need to engage consultants as they received the advice they needed from IMCRC or from discussions facilitated by IMCRC.

Cost savings: The value of costs saved through research conducted under the IMCRC Project.

Discussion with IMCRC has confirmed that IMCRC were clear regarding how this has been provided – i.e. direct cost savings due to IMCRC not a double counting of in-kind contributions

Project resulted in Customer Savings and Efficiencies: Savings and efficiencies for industry partner's customers as a result of the IMCRC.

Additional revenue: The value of increased sales or revenue as a result of the IMCRC project. Includes exports.

Note that inputs only cover R&D component of the project and do not consider future Sales, General and Administrative Expenses (SG&A) that are required post R&D to commercialise the product. ACIL Allen has made an assumption that SG&A accounts for 25% of revenue based on average SG&A costs for manufacturers.[25]

Note that the NPV generated from the cost benefit analysis is likely to be conservative. This is intentional given that many of the benefits occur in future, therefore it is preferable to underestimate potential benefits than overestimate them.

---

[25] SG&A of 25% has been assumed given that the manufacturing sector has an average SG&A of 10-25%, industrial has an average of 17% and Health Care and medical has an average of 42-50%. 25% has been chosen as a conservative estimate.
Refer:https://bench.co/blog/accounting/sga/#:~:text=What's%20a%20good%20SG%26A%20sales,to%20approach%2050%25%20of%20sales

https://www.netsuite.com/portal/resource/articles/accounting/selling-general-administrative-sga.shtml#:~:text=Typical%20SG%26A%20ratios%20vary%20widely,average%2010%25%E2%80%9320%25

https://saibooks.com/sga-benchmarks/

The Codex Bioreactor C

KEY FINDINGS

$2.1m cash and **$4.1m** in-kind support invested

$15.7m NPV of present and anticipated economic impacts identified to 2030. BCR of 3.35

The project has produced **a working prototype bioreactor**

4 full time equivalent jobs created (122 by 2030)

12 partnerships and collaborations

Alignment with Government priorities

Critical Technologies – biomaterials and Australian Medical Research and Innovation Priorities

C.1 Case study framework

This case study uses an evaluation framework that ACIL Allen has used to evaluate the impact and value of research done by a large number of research organisations.[26] The results of applying that framework to the Codex bioreactor case study are summarised in Figure C.1.

[26] The approach is based on that outlined in the CSIRO Impact Evaluation Guide. See https://www.csiro.au/~/media/About/Files/Our-impact-framework/CSIROImpactEvaluationGuide_Nov2015_WEB.pdf?la=en&hash=B351D24FB3CE02CB34FB859F2C34AA3940EE6D1F .

Figure C.1 Codex bioreactor Case Study – Impact Framework Diagram

INPUTS	ACTIVITIES	OUTPUTS	OUTCOMES	IMPACTS
– Research and development by Codex and Sydney University	– Research and development – Development of sensors to measure activity in real time – Development of software to control the bioreactor	– Bioreactor prototype which can be used as a research, teaching, testing and production tool	– Ability to assemble replacement arteries – The bioreactor has a wide range of potential research application s – The Bioreactor also has the potential to test new pharmaceuticals	– Impact in addressing cardio-vascular disease – Future impacts: – speeding the development of new pharmaceuticals, & – developing a better understanding of various human diseases.

Source: ACIL Allen

C.2 Background

C.2.1 The IMCRC

IMCRC is an independent and for-impact cooperative research centre with a successful, proven and scalable model for catalysing research and business partnerships that drives transformative commercial outcomes for participating Australian manufacturers. Through collaboration with businesses, research organisations, industry associations, and government they are able to co-fund, invest and advance research projects and the wider manufacturing sector. To date, IMCRC has successfully co-invested in more than 70 R&D projects in transformative manufacturing research.

The IMCRC provides its support under four Research Programs, namely:

1. Additive Manufacturing Processes – Here IMCRC's support is focussed on research to advance additive systems, develop and use new materials, improve process control, surface engineering, and to integrate creative design.
2. Automated and Assistive Technologies – This program supports R&D to improve the performance and effectiveness of production systems, such as robotics, automated technologies with perception and situation awareness capabilities.
3. High Value Product Development – This is aimed at developing high value products for domestic use and exports such as new electronic devices, diagnostic tools, and implantable materials.
4. Industrial Transformation – This program seeks to promote the transformation of manufacturing through industry education. It provides resources to help SMEs to assess and adopt emerging digital technologies and new business models.

In addition to the above four programs, the IMCRC launched the Activate program during the pandemic.

C.2.2 Codex and Sydney University

Codex Research (Codex) CEO Ed Brackenreg and Associate Prof Wise saw the limitations of laboratory cell assays as a challenge that needed addressing. For example, vascular cells are grown in flat plastic dishes, which is far removed from their environment in humans. Developing a bioreactor that closely simulated a human system would be a major advance. Their aim was to create a three-dimensional environment, giving the cells pressure, flow and other physical forces that better mimic human conditions – making the cells better models of biology and an improved tool for drug discovery and mechanistic studies.

Often medical research moves from plastic dishes to testing using animals. However, even in species that share common genes with humans, those genes can have different functions in different species, potentially reducing the relevance of research results to humans. There are also, of course, ethical concerns relating to animal-based research.

Codex Research (Codex), in collaboration with Sydney University, has developed a device called a bioreactor which grows patient-derived cells in a dynamic environment that closely mimics that of living human tissues. The bioreactor, which is now at advanced prototype stage, provides a much better environment for studying medical problems, without having to use animal models. This has been made possible because of the partnership between Codex Research CEO Ed Brackenreg and the Associate Professor Steven Wise's team at Sydney University.

> *There's no way we could possibly have made this progress alone, in-house, without partnering with experts working in a well-equipped lab, producing scientifically credible outcomes that then convince other funding bodies that the project is worth supporting through further development.*
>
> *Ed Brackenreg*

The Codex bioreactor project was funded under the IMCRC's Program 3: High Value Product Development Program

C.3 Inputs

IMCRC and Codex provided $6,192,198 in cash and in-kind contributions for this project (see Table C.1).

Other contributors were:

— $1,185,201 of non-staff in-kind contributions from industry and university partners

— $2,904,100 in-kind FTE contributions from industry and university partners

Table C.1 Financial and in-kind support for the Codex project

Contributor / Type of support	2018-19 ($)	2019-20 ($)	2020-21 ($)	2021-22 ($)	2022-23 ($)	Totals ($)
Cash						
IMCRC + Industry	147,015	420,325	643,738	574,851	316,968	2,102,897
Non-staff in kind						
Industry + University	54,934	155,013	230,616	373,198	371,440	1,185,201
Staff in kind						
Industry + University	312,000	703,000	718,000	760,100	411,000	2,904,100
Total	**513,949**	**1,278,338**	**1,592,354**	**1,708,149**	**1,099,408**	**6,192,198**

Note: Value of the staff in kind input (Industry + University) into the IMCRC project is the cash equivalent for salaries calculated at Commonwealth determined rates at establishment of IMCRC.

Source: IMCRC

C.4 Activities

The IMCRC project described in this case study focussed on developing the Codex bioreactor technology to mimic the human vasculature system and, in particular, to facilitate materials research on vascular grafts. Treating cardiovascular disease often requires grafts to bypass blocked arteries. Developing new, more versatile graft materials and improving how grafts interact with and regulate the growth of vascular cells has driven this example of the use of the bioreactor in which the performance of different graft materials can be developed and tested. Importantly, this sort of testing cannot readily be done in a plastic (petri) dish.

Applying advanced manufacturing technologies including computer-aided design, 3D printing and electronics, the project manufactured custom designed components of the bioreactor technology. Researchers then integrated automated, flexible manufacturing strategies to facilitate the production of the bioreactor system and the use advanced sensing technology to achieve real-time monitoring and control of its physical parameters.

While initially optimised for the development of tissue engineered vascular grafts, the bioreactor will serve as a base technology upon which different applications can be built. This will allow Codex Research to access clinical, regenerative medicine, and medical science research markets.

C.5 Outputs

Outputs from the IMCRC project are:

— The development of "a blood-vessel-in-a-box" – a novel perfusion bioreactor – for research and clinical applications, which grows patient-derived cells in a dynamic environment that closely mimics that of living human tissue

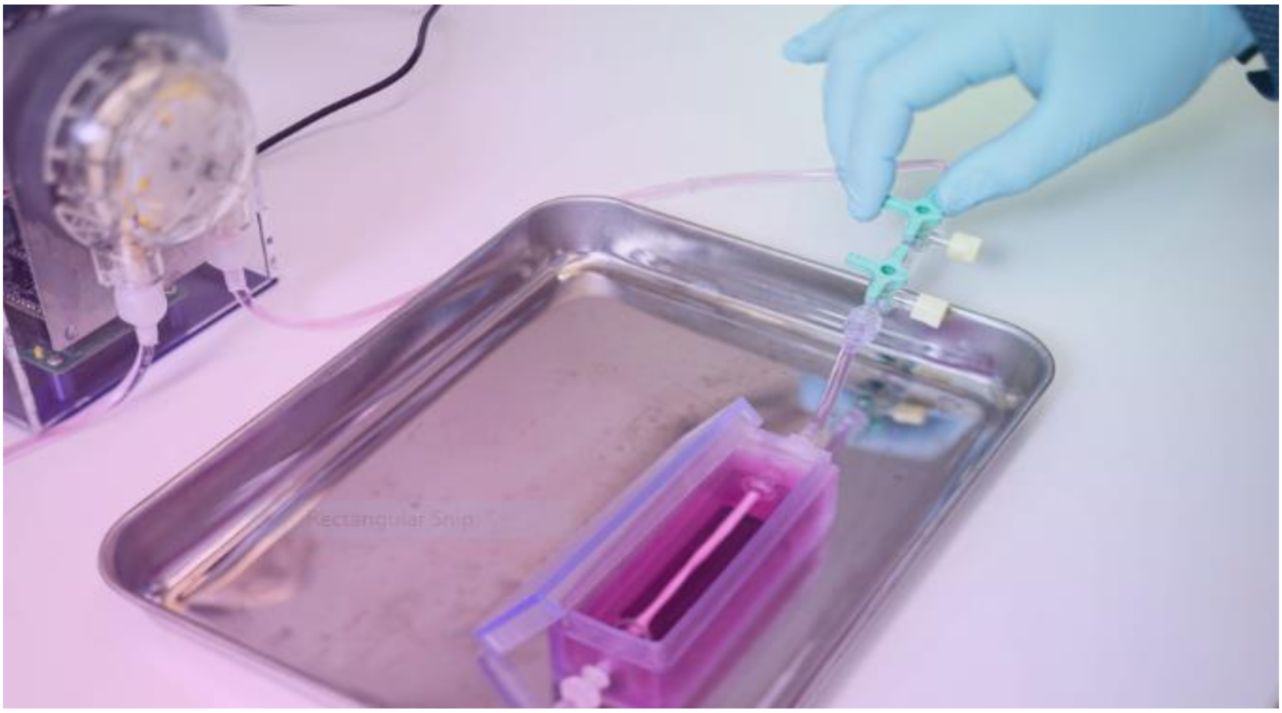
— Use of Industry 4.0 and 3D printing has allowed rapid development and prototyping of fully functioning bioreactors with the development of a full working prototype including programable pressure and flow simulation to show direct effects on cell grows compared to static "dish" growth. (Michael *et al*, 2022))

— Concurrent business innovation to look at service and supply models for labs allowing a "Coffee Pod" analogy for supplying grafts and cell seeding for laboratory services.

— Significant participation with the University of Sydney Business School undergraduate program to look at business innovation Including participation in Sydney University Incubate Program

The bioreactor provides a sterile environment where temperature and other variables can be controlled, as well as a providing a supply of nutrients and removing waste. In addition, the bioreactor's pulsed pumping system, simulates the blood flows created by the human heart. A porous tubular scaffold in the bioreactor provides an anchor for initial cell attachment and growth. Distributing cell growth evenly is achieved through automated dynamic cell seeding. The whole process is monitored with sensors that provide information to the control software in real time.

Figure C.2 Growing human cells on a scaffold under the control of the bioreactor



Source: Codex Research, accessed on 17 September 2022 at https://www.codexresearch.com.au/index.html

While at first optimised for the development of tissue engineered vascular grafts, the bioreactor will serve as a base technology upon which different applications can be built. This will allow Codex Research to access clinical, regenerative medicine, and medical science research markets.

In medical research, new pharmaceuticals and products for treating medical conditions are developed in laboratories and tested on animals before being trialled in humans. Unfortunately, in many cases, products that work in animals do not work in humans. In addition, genetic and environmental variation between humans means that adverse reactions can still occur even after these products have passed human trials. The bioreactor has the potential to replace animal trials.

Innovation

The bioreactor is a significant innovation. Its use in medical research will bring about innovations in the training of cardiologists, new medical practices and the testing of pharmaceuticals.

Publications

Michael PL, Yang N, Moore M, Santos M, Lam YT, Ward A, Hung JC, Tan RP and Wise SG, 2022, Synthetic vascular graft with spatially distinct architecture for rapid biomimetic cell organisation in a perfusion bioreactor, Biomedical Materials, **17**, 045001

C.6 Outcomes

The main outcome is the development of a working prototype Bioreactor. The team is now attracting significant funding from other sources and a permanent team has been established at Sydney University to further develop this innovation.

Adoption

At this stage, the adoption is limited to studies in Associate Professor Wises' laboratory, enabling execution of National Heart Foundation Vanguard grant (collaborative with Prof Gemma Figtree) and grants from Diabetes Australia grants. Bioreactors are now being rolled out to early adopter labs at UNSW, Garvan, Kolling Inst and others.

Alignment with government strategic priorities

The Australian Government's 2021 List of Critical Technologies in the National Interest includes biomaterials - Natural or synthetic materials that can safely interact with biological systems (e.g. the human body) to support medical treatment or diagnosis. Applications for biomaterials include medical implants, such as artificial joints and heart valves, scaffolds to promote bone and tissue regrowth, biosensors and targeted drug delivery systems.

The Australian Medical Research and Innovation Priorities 2020-2022 include Translational Research Infrastructure to address gaps in early biomedical and medical technology product development by supporting access to expertise and infrastructure in partnership with industry that seeks to accelerate rapid pre-clinical work and evaluation and build sustainability in the sector.

C.7 Impacts

C.7.1 Role of IMCRC

IMCRC provided funding and advice. IMCRC also brought a commercial focus to this research and development project. In addition to providing expertise from their own team, the IMCRC was able to suggest names of people who could help address some of the challenges. Conversations with some of these contacts provided information that would not otherwise have had. Medical research laboratories tend to be focussed on biology, but IMCRC understood the manufacturing issues.

IMCRC sponsored the Sydney University research team to complete the Cruxes Accord Program (based on CSIRO's On Program). The team participated in market studies and interviewed more than one hundred potential users. This led to the development of another grant application.

C.7.2 Economic impacts

In the near term the market for the bioreactor is expected to be for research. The number of research groups around the world that might wish to purchase the bioreactor is quite large. In the medium term, the bioreactor has clinical applications in cardiology. The longer-term market depends on the outcome of further research and development using the bioreactor in applications ranging from organ transplants to cancer.

Table C.2 shows the results of the Cost Benefit Analysis (CBA) of the project at the 3, 7 and 10 per cent discount rates.

The inputs in Table C.1, adjusted to 2021-22 dollars, have been included as the costs. The benefits include cost savings, cost, avoidance and additional revenue for Codex. The 7 per cent rate is the central rate recommended by the Commonwealth Government for best-practice CBA, with the 3 and 10 per cent rates included as a sensitivity test. The results of the CBA show that the net impact is positive at all three discount rates.

At a discount rate of 7 per cent, the Net Present Value (NPV) is expected to be $15,674,675 over the analysis period (2016-17 to 2029-30), and the BCR is 3.35. A BCR above one suggests that the benefits can be expected to outweigh the costs of the project.

Table C.2 NPV of economic impacts of the Codex project at 3, 7, and 10 per cent discount rates (20210-22 dollars)

	Discount rate 3% ($)	Discount rate 7% ($)	Discount rate 10% ($)
Costs	$6,461,441	$6,670,129	$6,834,974
Benefits	$28,568,331	$22,344,803	$18,726,716
Net Present Value	**$22,106,890**	**$15,674,675**	**$11,891,742**
BCR	**4.42**	**3.35**	**2.74**

Source: data provided by Codex to IMCRC

Note that the benefits reported by Codex have been adjusted to consider the attribution of benefits to IMCRC, as well as expected costs relating to selling, general and administrative expenses. The analysis period was from 2016-17 to 2029-30

C.7.3 Other impacts

The biggest social impacts from this project are, initially, in improvements to better understand the biology of vascular cells in settings that better reflect their environment in the native vasculature. At present the focus in on uncovering new mechanisms of disease and new materials that better support vascular cell growth.

Employment impacts

Codex expects to employ three FTE (one researcher and one degree-qualified employee) in 2022-23, which will rise to 122 FTE employees (two researchers, 20 degree-qualified employees, and 100 Trade/Diploma qualified employees) by 2029-30 as a result of the project. This is equivalent to 254 FTE job-years over the analysis period.

Educational impacts

Codex expects a total of one student completion over 2019-20 to 2022-24.

Partnerships and collaborations

Codex expects a total of 12 partnerships and collaborations between 2018-19 and 2023-24. Codex estimates that there will 10 Australian collaborations, one Australian Partnership, and one further collaboration planned between Codex and the project research partner.

The project has also involved collaboration between the Sydney University research team and the University of NSW (prototype testing) and the University of Western Sydney (injection moulding operations, and design).

Uptake in technology

Codex expects to adopt, trial, and experiment with new technology 6 times between 2019-20 and 2023-24. The areas of new technology that have/will be explored are additive manufacturing/3D printing; virtual or augmented reality; advanced materials; sensors and data analytics; machine learning/artificial intelligence; and robotics and automation.

C.8 Potential future impacts

Codex identified the following potential future applications of the technology they have developed:

— In research to design and test new materials (like grafts) and devices (like balloons and stents) and testing them in conditions that mimic those in humans

— Codex's NHF project is looking at cells from 5000 CVD patients and screening them for new mechanisms of disease prevention

— Codex's DART project is looking at the mechanism of endothelial cell dysfunction in the context of diabetes

— There is potential for wider use in tissue engineering (e.g. wound repair) or in other fields such as cancer research (looking at metastasis and invasion phenomena)

Codex also suggested that there could be some restoration of sovereign manufacturing capability including CNC machining, injection moulding, etc., for biomedical applications – that extend beyond the bioreactor.

Whiteley Corp Managing Biofilms

D

KEY FINDINGS

$5.54m invested by IMCRC, Whiteley and partners

$7.2m NPV of present and anticipated economic impacts identified to 2030. BCR of 2.16

The project has produced **biofilm removal treatments**

13 full time equivalent jobs created by 2029-30

3 partnerships and collaborations

Alignment with Government priorities

Antimicrobial resistance

Modern Manufacturing Initiative

D.1 Case study framework

This case study uses an evaluation framework that ACIL Allen has used to evaluate the impact and value of research done by a large number of research organisations.[27] The results of applying that framework to the Whiteley Corporation case study are summarised in Figure D.1.

[27] The approach is based on that outlined in the CSIRO Impact Evaluation Guide. See https://www.csiro.au/~/media/About/Files/Our-impact-framework/CSIROImpactEvaluationGuide_Nov2015_WEB.pdf?la=en&hash=B351D24FB3CE02CB34FB859F2C34AA3940EE6D1F .

Figure D.1 Whiteley Corporation Case Study – Impact Framework Diagram

INPUTS	ACTIVITIES	OUTPUTS	OUTCOMES	IMPACTS
– Investment in research and development by Whiteley and Sydney University	– Collaborative research and development – Testing – Patenting	– Product for removing biofilms from dental and equipment – Product for dealing with biofilms in chronic wounds	– October 2022 launch of product for dentists – Launch of product to remove biofilms from endoscopes[28] scheduled for 2023	– Risk of infection in dentistry reduced – Improved sterilisation of surgical instruments

Source: ACIL Allen

D.2 Background

D.2.1 The IMCRC

IMCRC is an independent and for-impact cooperative research centre with a successful, proven and scalable model for catalysing research and business partnerships that drives transformative commercial outcomes for participating Australian manufacturers. Through collaboration with businesses, research organisations, industry associations, and government they are able to co-fund, invest and advance research projects and the wider manufacturing sector. To date, IMCRC has successfully co-invested in more than 70 R&D projects in transformative manufacturing research.

The IMCRC provides its support under four programs, namely:

1. Additive Manufacturing Processes – Here IMCRC's support is focussed on research to advance additive systems, develop and use new materials, improve process control, surface engineering, and to integrate creative design.
2. Automated and Assistive Technologies – This program supports R&D to improve the performance and effectiveness of production systems, such as robotics, automated technologies with perception and situation awareness capabilities.
3. High Value Product Development – This is aimed at developing high value products for domestic use and exports such as new electronic devices, diagnostic tools, and implantable materials.
4. Industrial Transformation – This program seeks to promote the transformation of manufacturing through industry education. It provides resources to help SMEs to assess and adopt emerging digital technologies and new business models.

In addition to the above four programs, the IMCRC launched the Activate program during the pandemic.

D.2.2 Whiteley Corporation, Sydney University and University of NSW

Up to 80 per cent of human bacterial infections are biofilm associated. Biofilms formed by bacteria can attach to living and non-living surfaces, such as implants and indwelling medical devices such as catheters, where they pose a significant infection risk for patients. Biofilms are also responsible for contamination in industrial and institutional settings, where they are expensive to remove and cause damage to surfaces.

This project has taken a new approach to resolving bacterial biofilm problems in humans and industrial settings, through mimicking natural and synergistic multimodal strategies. Whiteley Corporation (Whiteley) together with the University of Sydney and University of NSW has developed several new therapeutic treatments for biofilm mediated infection, that effectively disrupt the formation of biofilm and eradicate underlying bacteria found, for instance, in the lungs of cystic fibrosis patients, chronic urinary tract infections and burn wounds. There are industrial applications for the project's outcomes on dry and wet surfaces, in the food industry and for industrial oil, gas and water pipes.

Using advanced manufacturing design methods combined with Industry 4.0 manufacturing processes, the project has developed and manufactured small/highly customisable high-value products in a Good Manufacturing Product environment, including novel packing and a dosage delivery device.

The development and manufacturing of formulations for different applications and carriers, (e.g. gels, foams and coatings) are key to the products' successes.

D.3 Inputs

IMCRC and Whiteley provided $2,169,621 in cash and in-kind contributions for this project (see Table D.1**).** Other contributions were:

— $753,709 of non-staff in-kind contributions from industry and university partners

— $2,617,600 in-kind contributions from industry and university partners

Table D.1 Financial and in-kind support for the Whiteley project

Contributor / Type of support	2017-18 ($)	2018-19 ($)	2019-20 ($)	2020-21 ($)	2021-22 ($)	2022-23 ($)	Totals ($)
Cash							
IMCRC + Industry	-	379,540	484,120	451,280	636,068	218,613	**2,169,621**
Non-staff in kind							
Industry + University	-	116,262	193,037	166,122	229,074	49,214	**733,709**
Staff in kind							
Industry + University	72,000	717,800	504,050	491,900	731,800	100,050	**2,617,600**
Total	**72,000**	**1,213,602**	**1,181,207**	**1,109,302**	**1,596,942**	**367,877**	**5,540,930**

Note: Value of the staff in kind input (Industry + University) into the IMCRC project is the cash equivalent for salaries calculated at Commonwealth determined rates at establishment of IMCRC.
Source: IMCRC

D.4 Activities

The project undertaken by Whiteley Corporation and its university partners has involved the research and development of new therapeutic treatments for biofilm mediated infections, building on work by Associate Professor Jim Manos and his team at Sydney University. A team at the University of NSW, led by Professor Mark Willcox, developed anti-biofilm peptide compounds to be included in formulations created in conjunction with University of Sydney, that can be used as treatments for wounds and cystic fibrosis.

The peptide compounds have been either targeted at biofilm disruption or biofilm inhibition. They can aid in the development of new treatments to reduce microbial load for wounds to improve healing. The new patented compounds were added into formulations by Whiteley Corporation and then sent back to both UNSW and the University of Sydney for further testing.

D.5 Outputs

The project has resulted in the development of number of multi-modal formulations for biofilm disruption for infections including diabetic leg wounds, urinary tract infections and infections impacting people with cystic fibrosis. Following the research and testing of new formulations, manufacturing processes have been developed for commercial production of the components of the formulations, under GMP conditions.

Innovation

The innovation in this project lies in the development of the new formulations. which have been shown to be effective in vitro.

Publications

Some of the publications associated with this project are listed below:

- Ashish Kumar T, Paino D, Manoharan A, Farrell J, Whiteley G, Kriel F, Glasbey T, Manos J, 2019. Conditions Under Which Glutathione Disrupts the Biofilms and Improves Antibiotic Efficacy of Both ESKAPE and Non-ESKAPE Species. Frontiers in Microbiology, **10**, 1-16
- Manoharan A, Das T, Whiteley GS, Glasbey T, Kriel FH, Manos J, 2020, The effect of N-acetylcysteine in a combined antibiofilm treatment against antibiotic-resistant Staphylococcus aureus, Journal of Antimicrobial Chemotherapy, **75**, Issue 7, July 2020, 1787–1798, https://doi.org/10.1093/jac/dkaa093
- Aiyer A, Manoharan A, Paino D, Farrell J, Whiteley GS, Kriel FH, Glasbey TO, Manos J, Das T, 2021, Disruption of biofilms and killing of Burkholderia cenocepacia from cystic fibrosis lung using an antioxidant-antibiotic combination therapy. Int J Antimicrob Agents. Aug;58(2):106372. doi: 10.1016/j.ijantimicag.2021.106372. Epub 2021 Jun 8. PMID: 34116184.
- Aiyer A, Visser SK, Bye P, Britton WJ, Whiteley GS, Glasbey T, Kriel FH, Farrell J, Das T, Manos J, 2021, Effect of N-Acetylcysteine in Combination with Antibiotics on the Biofilms of Three Cystic Fibrosis Pathogens of Emerging Importance. Antibiotics, **10**, 1176. https://doi.org/10.3390/antibiotics10101176
- Manoharan A, Ognenovska S, Paino D, Whiteley G, Glasbey T, Kriel FH, Farrell J, Moore KH, Manos J, Das T, 2021, N-Acetylcysteine Protects Bladder Epithelial Cells from Bacterial Invasion and Displays Antibiofilm Activity against Urinary Tract Bacterial Pathogens. Antibiotics (Basel), Jul 23;10(8):900. doi: 10.3390/antibiotics10080900. PMID: 34438950; PMCID: PMC8388742.
- Das T, Sabir S, Chen R, Farrell J, Kriel F, Whiteley G, Glasbey T, Manos J, Willcox M, Kuma, N, 2022. Halogenated Dihydropyrrol-2-One Molecules Inhibit Pyocyanin Biosynthesis by Blocking the Pseudomonas Quinolone Signaling System. Molecules, 27(4), 1169.
- Aiyer A, Manos J, 2022, The Use of Artificial Sputum Media to Enhance Investigation and Subsequent Treatment of Cystic Fibrosis Bacterial Infections. Microorganisms. Jun 22;**10**(7):1269. doi: 10.3390/microorganisms10071269. PMID: 35888988; PMCID: PMC9318996.

Conference presentations

Some of the conference presentations associated with this project are listed below:

- Aiyer A, 2021, Antioxidant-antibiotic combination significantly disrupts Burkholderia cenocepacia biofilms from cystic fibrosis clinical isolates and kills the sessile cells, Australian Society of Microbiology Conference 2021
- Manoharan A, 2021, The therapeutic potential of N acetyl cysteine in combatting biofilm formation in urinary tract infections. Australian Society of Microbiology Conference 2021
- Manoharan A, 2022, Disarming Proteus mirabilis and blowing its cover: N acetylcysteine inhibits P. mirabilis urease activity and prevents catheter encrustation due to biofilm formation in catheter associated UTIs, Australian Society of Microbiology Conference 2022
- Aiyer A, 2022, Investigating the efficacy of antioxidant-antibiotic combination therapy on *Achromobacter xylosoxidans* in a cystic fibrosis lung cell model, Australian Society of Microbiology Conference 2022

Patents

- BIOFILM DISRUPTING COMPOSITION FOR USE ON CHRONIC WOUNDS, Notice of Allowance, 2022

D.6 Outcomes

A new and effective biofilm treatment has been developed. Its initial application will be in dental surgeries. This will reduce the risk of infections.

Work is well advanced on a product to address the biofilm problem in endoscopes.[29] This product will be marketed from mid-2023.

One of the outcomes of this project is significant collaboration including the integration and funding of a second University (UNSW), into the project to utilise novel peptide formulations developed within the team.

Adoption

Adoption of this formulation for managing biofilms in dentistry will commence in October 2022. The adoption of this product for endoscopes will take place mid-2023.

Alignment with government strategic priorities

The outcomes of this project align with the Commonwealth Government's priority of addressing antimicrobial resistance. In addition, the Government's Modern Manufacturing Initiative lists medical products and a national manufacturing priority.

D.7 Impacts

The use of the products from this project are expected to reduce the incidence of infections from surgical and dental equipment.

This project will not only have benefits to human health and the industrial sector but will also benefit the Australian manufacturing and supply chain, as well as job creation in the Hunter Region of NSW where Whiteley Corporations production facility is located.

Role of IMCRC

In addition to providing financial assistance, the IMCRC provided access to advice on new GMP production and scaling of manufacturing, which has resulted in a new fully automated (Industry 4.0) production system.

> *The IMCRC's approach is an innovation pathway that really facilitates collaboration. All parties to the project know their role and responsibilities and we are all singularly focussed on achieving the desired commercial outcomes together.*

Dr Greg Whiteley
Executive Chairman, Whiteley Corporation

D.7.1 Economic impacts

The economic impacts of this project will arise initially from its application in dentistry and, if the future, its application in reducing the risk of infection from surgical instruments and implants. In the longer term, there are likely to benefits from controlling infection in wounds. Table D.2 shows the results of the Cost Benefit Analysis (CBA) of the project at the 3, 7 and 10 per cent discount rates.

[29] Endoscopes are flexible instruments that combine fibre-optics and charge-coupled devices to facilitate illumination and visualization of otherwise inaccessible sites, such as hollow organs.

Table D.2 NPV of economic impacts of Whiteley project at 3, 7, and 10 per cent discount rates (2021-22 dollars)

	Discount rate 3%	Discount rate 7%	Discount rate 10%
Costs	$5,914,233	$6,233,042	$6,485,064
Benefits	$16,848,354	$13,438,098	$11,434,691
Net Present Value	**$10,934,122**	**$7,205,057**	**$4,949,627**
BCR	**2.85**	**2.16**	**1.76**

Source: data provided by Whiteley to IMCRC

Note that the benefits reported by Whiteley have been adjusted to consider the attribution of benefits to IMCRC, as well as expected costs relating to selling, general and administrative expenses. The analysis period was from 2016-17 to 2029-30

The inputs in Table D.1, adjusted to 2021-22 dollars, have been included as the costs. The benefits include cost savings, cost, avoidance and additional revenue for Whiteley. The 7 per cent rate is the central rate recommended by the Commonwealth Government for best-practice CBA, with the 3 and 10 per cent rates included as a sensitivity test. The results of the CBA show that the net impact is positive at all three discount rates.

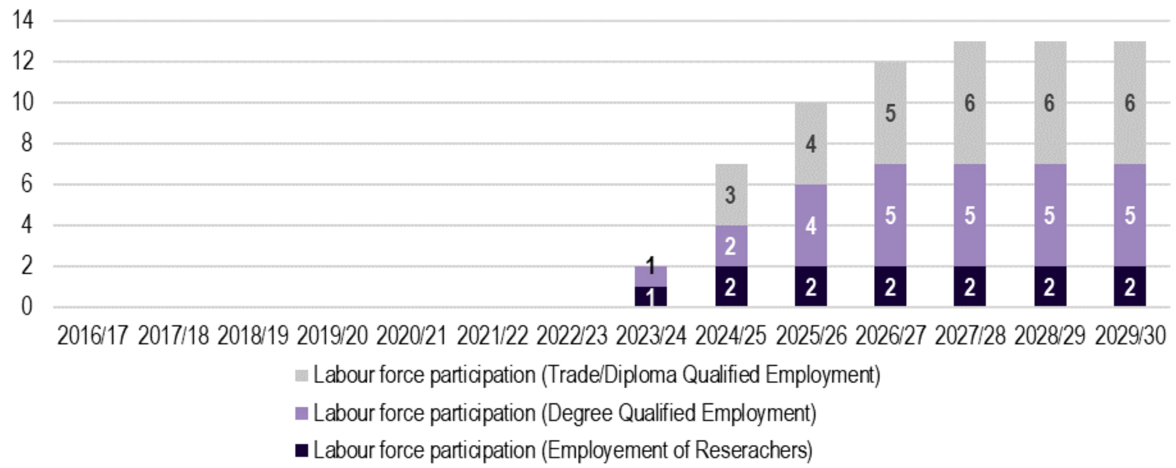
At a discount rate of 7 per cent, the Net Present Value (NPV) is expected to be $7,205,057over the analysis period (2016-17 to 2029-30), and the BCR is 2.16. A BCR above one suggests that the benefits can be expected to outweigh the costs of the project.

D.7.2 Other impacts

Employment impacts

Whiteley expects to employ two FTE (one researcher and one degree-qualified employee) in 2023-24, which will rise to 13 FTE employees (two researchers, five degree-qualified employees, and six Trade/Diploma qualified employees) from 2026-27 to 2029-30. This is equivalent to 83 FTE job-years over the analysis period.

Figure D.2 Employment by employee category - Whiteley



Source: ACIL Allen based on Whiteley labour force participation data

Total FTE job-years over analysis period = 83

Educational impacts

Whiteley expects to support one postgraduate student completion over 2018-19 to 2022-23.

Partnerships and collaborations

Whiteley have reported 2 Australian collaborations and one Australian partnership as a result of the IMCRC project between 2018-19 and 2022/23. The project partners are engaged in ongoing collaborative research to develop further applications of the outcomes of the work supported by the IMCRC.

Uptake in technology

Whitely expects to adopt, trial, and experiment with new technology twice between 2019-20 and 2023-24. The areas of new technology that have/will be explored are additive manufacturing/3D printing, and robotics and automation.

D.8 Potential future impacts

The products developed to date from this project have strong export potential. The project is also expected to lead to a means of treating chronic wounds.

FormFlow

E

KEY FINDINGS

$207,000 invested by **IMCRC** and **industry partners**

$12.6m NPV of present and anticipated economic impacts identified to 2029-30 (7% DR). BCR of 21.11.

$385,000 non-staff and **FTE in-kind** investment

12 full time equivalent job-years created (1.5 FTE over 8 years)

The project has produced a **2D laser system** that enables continuous, **real-time quality control**, and **new forming technology** to produce a **corrugated corner bend from flat sheet**

Alignment with Australian Government's **Recycling & Clean Energy** National Manufacturing Priority

This case study uses an evaluation framework that ACIL Allen has used to evaluate the impact and value of research done by a large number of research organisations.[30] The results of applying that framework to the FormFlow case study are summarised in Figure E.1.

[30] The approach is based on that outlined in the CSIRO Impact Evaluation Guide. See https://www.csiro.au/~/media/About/Files/Our-impact-framework/CSIROImpactEvaluationGuide_Nov2015_WEB.pdf?la=en&hash=B351D24FB3CE02CB34FB859F2C34AA3940EE6D1F .

E.1 Case study framework

Figure E.1 FormFlow Case Study – Impact Framework

INPUTS	ACTIVITIES	OUTPUTS	OUTCOMES	IMPACTS
– $591,536 of in-kind and cash funding.	– Collaboration between Deakin and FormFlow to improve existing FormFlow bend technology and process. – Other collaborators included Austeng, BlueScope, and the school of architecture, construction management and civil engineering at Deakin University.	– A 2D laser system that enables the manufacturer to perform continuous, real-time quality control – A new forming technology to produce a corrugated corner bend from a flat sheet of steel – Awards, and design registrations.	– Adoption of improved process in FormFlow's modular housing business. For example, the Veranda Fire House, which incorporates the FormFlow C90 bend which creates a 'no gaps' barrier against ember attacks.	– $11,469,000 NPV of present and anticipated economic impacts identified to 2029/30 (7% DR). BCR of 19.35. – Employment opportunities – Uptake of technology that improves safety and resilience – Ongoing partnerships and collaborations.

E.2 Background

E.2.1 The IMCRC

IMCRC is an independent and for-impact cooperative research centre with a successful, proven and scalable model for catalysing research and business partnerships that drives transformative commercial outcomes for participating Australian manufacturers. Through collaboration with businesses, research organisations, industry associations, and government they are able to co-fund, invest and advance research projects and the wider manufacturing sector. To date, IMCRC has successfully co-invested in more than 70 R&D projects in transformative manufacturing research.

The IMCRC provides its support under four programs, namely:

1. Additive Manufacturing Processes – Here IMCRC's support is focussed on research to advance additive systems, develop and use new materials, improve process control, surface engineering, and to integrate creative design.
2. Automated and Assistive Technologies – This program supports R&D to improve the performance and effectiveness of production systems, such as robotics, automated technologies with perception and situation awareness capabilities.
3. High Value Product Development – This is aimed at developing high value products for domestic use and exports such as new electronic devices, diagnostic tools, and implantable materials.
4. Industrial Transformation – This program seeks to promote the transformation of manufacturing through industry education. It provides resources to help SMEs to assess and adopt emerging digital technologies and new business models.

In addition to the above four programs the IMCRC launched the Activate program during the pandemic.

The Activate program was designed to stimulate collaborative investment and provide opportunities for manufacturing SMEs to invest in smaller R&D projects. The program offers manufacturers access to R&D expertise and matched cash funding between $50,000 – $100,000 for shorter-term, industry-led research projects intended to advance manufacturing and digital technologies (Industry 4.0).

E.2.2 FormFlow and Deakin University

Founded in 2016, FormFlow is a Geelong-based engineering start-up developing and commercialising new manufacturing solutions for the building industry. The business' first project included the development of the C90 bend, a revolutionary bending process to produce a sharp 90-degree bend in a corrugated sheet resulting in an airtight corner piece of corrugated metal that acts as a structural joint. FormFlow now has a series of technologies in production and in the research and development phase which are collectively referred to as FormFlow Bend technology.

FormFlow's goal is to develop advanced technologies to make high performance habitable spaces that are affordable, attractive and functional for Australians. FormFlow has already integrated some of these advanced technologies into a prefabricated building system to launch its "FormFlow Living" product range.

FormFlow's university partner for the IMCRC project was Deakin University. Located in Geelong Victoria, Deakin is one of Australia's leading tertiary education providers. Deakin offers practical, industry-designed courses in areas including architecture, design, engineering, IT, business, education, health, science, and sport.

The FormFlow project was funded under the IMCRC's Activate program.

E.3 Inputs

IMCRC and FormFlow provided $207,000 in cash contributions for this project (see Table E.1). Other contributions were:

— $111,541 of non-staff in-kind contributions from industry and university partners
— $273,000 in-kind FTE contributions from industry and university partners

Table E.1 Support for the FormFlow project

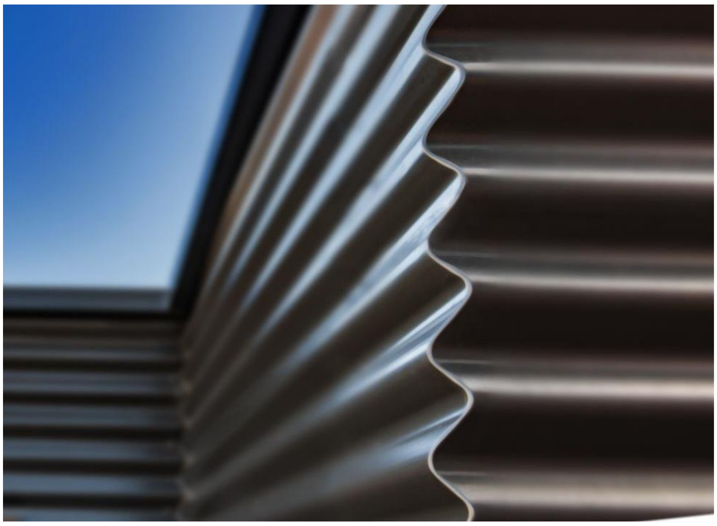
Contributor / Type of support	2020/21	2021/22	2022/23	Total
Cash				
IMCRC + Industry	$136,497	$70,498	-	$206,995
Non-staff in kind				
Industry + University	$56,281	$55,260	-	$111,541
Staff in kind				
Industry + University	$139,500	$133,500	-	$273,000
Total	**$332,278**	**$259,258**	**-**	**$591,536**

Note: Value of the staff in kind input (Industry + University) into the IMCRC project is the cash equivalent for salaries calculated at Commonwealth determined rates at establishment of IMCRC.
Source: IMCRC

E.4 Activities

This IMCRC project focused on improving the process of manufacturing FormFlow's foundation technology, the C90 bend. The C90 bend technology was patented by FormFlow in 2016. It was a world first innovation that enabled the formation of a 90-degree bend in corrugated sheets without damaging the material's structure or coating. The technology forms a continuous corner that allows seamless joins between walls and roofing (see Figure E.2).

Figure E.2 Example of FormFlow's C90 bend



Source: https://formflow.net.au/products/c90/

The IMCRC project was established to meet FormFlow and corrugated sheet manufacturer's quality control needs. In the early stages of manufacturing, FormFlow realised that the best results when manufacturing the C90 bend were achieved when the shape of the initial corrugated sheet had a consistent specification and profile. FormFlow therefore set out to develop technology which would help improve the product quality of inputs as well as the repeatability of FormFlow's bend.

IMCRC's funding helped FormFlow to purchase equipment and hire the expertise needed to develop the technology that would not only address quality control needs, but also improve FormFlow's manufacturing processes. The outputs of the project (discussed in more detail in the section below) were:

— A 2D laser system that enables the manufacturer to perform continuous, real-time quality control

— A new forming technology capable of producing a corrugated corner bend from a flat sheet of steel

The project, which ran for 12 months, commenced in November of 2020. FormFlow purchased hardware for the laser system, installed a sheet bending press and developed the first prototype of the forming technology with the funding from IMCRC. A part-time RMIT student was also hired to develop the program for the laser system.

FormFlow noted that the timing of these activities was critical. Although FormFlow had applied for an ARC Linkage Grant, the IMCRC's process from drafting to approval of the funding support for the project was much faster than the ARC scheme, meaning that R&D work was able to commence almost immediately.[31] The IMCRC's funding was critical in allowing FormFlow to purchase equipment and hardware required to undertake the project.

FormFlow advised that they collaborated with a wide range of groups during the project, including staff from the local engineering firm Austeng, flat product steel producer BlueScope (who owns Lysaght) and the School of Architecture, Construction Management and Civil Engineering at Deakin University.

E.5 Outputs

A description of outputs from the IMCRC project are provided below.

Innovation

The project led to the following innovations:

— A 2D laser system that enables the manufacturer to perform continuous, real-time quality control

[31] FormFlow estimated that the timeframe for a decision on IMCRC support is around 1-2 months, compared to the ARC which on average has a turnaround time of 12 months.

- The 2D profile scanner combines a high-resolution laser with evaluation software to monitor the shape of building products before and after they are manufactured into FormFlow products or integrated into FormFlow's building systems. The system can be integrated into a specific manufacturing facility to monitor shape. It can also be moved between forming machines for trouble shooting and tool adjustment purposes.
- This technology provides companies with the capability to maintain tighter control over the shape of parts they make which improves their product quality and reduces waste. This is useful for corrugated sheet manufacturers like Lysaght, but also any company that requires accurate shape control of the products they make.

— A new forming technology capable of producing an in-phase corrugated corner bend from a flat sheet of steel

- The new forming technology allows the manufacture of FormFlow's C90 corner from a flat sheet of steel. This eliminates the need for pre roll formed corrugated sheet feed stock thereby reducing costs and improving product quality. To validate the new forming concept a hydraulic manufacturing facility was installed at FormFlow using 3D printed prototype tools. This achieved FormFlow's new In-phase corner product. The IP for the shape is now protected by a design registration. As the process development progresses further IP will be filed.

The project also led to a design registration being filed in multiple countries.

In-phase corrugated corner

Source: FormFlow

Awards

FormFlow was the winner of the 2021 Australian Technologies Competition's Advanced Manufacturing Award.[32]

E.6 Outcomes

IMCRC's adaptability during the IMCRC project supported changes in FormFlow's processes which led to new discoveries and opportunities. The project led to new business opportunities including modular building systems to delivery high quality, affordable housing rapidly and at high volumes. The company has used their technologies to deliver a range of housing solutions to address, amongst other things, bushfire resilience, and rapid response disaster relief housing. Some of these are discussed below.

Adoption of technology for FormFlow Living and the Veranda Fire House

FormFlow Living is FormFlow's modular housing building system. It leverages FormFlow's world-first corrugated bend technology to create customisable prefabricated living spaces that are durable and energy efficient.

FormFlow advertises a number of potential designs on its website, which includes studios and modular housing with customisable bedroom and bathroom capacity. One of the designs advertised is the Veranda Fire House, which was created in collaboration with Ian Weir, one of the country's leading architects in the design of Australian bushfire-safe homes (see Figure E.3).

[32] https://amtil.com.au/australias-11-best-technology-scaleups-are-crowned-for-2021/

Figure E.3 Form Flow's Veranda Fire House

Source: https://formflow.net.au/living/spaces/veranda-fire-house/

Ian, in collaboration with FormFlow, leveraged his understanding of AS3959 (the Australian Standards for Building in Bushfire Prone Areas) to design the Veranda Fire House to withstand extreme levels of bushfire attack. Up to 85% of homes that burn down during a bushfire are the result of an ember attack. The Veranda Fire House features the FormFlow C90 bend to create a 'no gaps' barrier against ember attacks and extreme heat. The Veranda Fire House can be configured multiple ways including as a commercial building or a bushfire proof residential home. The Veranda Fire House utilises a modular galvanised steel frame. These modular structures are manufactured offsite and delivered to site in much less time than a conventional build. The versatility of the Veranda Fire House concept means that customers can start small and add sections or modules to their home or commercial space as their needs change over time.

Alignment with government strategic priorities

FormFlow's project aligns with the Australian Government's Recycling & Clean Energy National Manufacturing Priority. FormFlow is developing steel construction solutions using its FormFlow bend technology to enable energy-efficient and low-carbon homes. The FormFlow bend is manufactured from Colorbond Steel which is produced from more than 20 per cent recycled material. Steel is 100 per cent recyclable and the most recycled material in the world with a potentially endless lifecycle. Environmental impact is further reduced over the buildings' life cycle, and the life span of the structure extended, through its modular design which allows for disassembly and reuse.[33] It also aligns with the Government's *Making science and technology work for industry* Modern Manufacturing pillar, as it supports digital transformation through its 2D laser quality monitoring and evaluation software.

E.7 Impacts

E.7.1 Role of IMCRC

The IMCRC supported FormFlow to purchase the equipment needed to make significant improvements to the FormFlow bend development process. According to Dr Mattias Weiss, FormFlow's university partner from Deakin University:

> *We weren't able to control the shapes easily, so we did a complete U-turn and developed a new process which proved to be a great success. That turnaround would not have been possible without the IMCRC funding, which allowed us to install a press and develop the first prototype of the new process.*

[33] https://formflow.net.au/living/

Dr Mattias Weiss and Dr Matt Dingle (Managing Director at FormFlow) explained that IMCRC funding helped FormFlow to understand the defects in the existing FormFlow bend technology:

> *It was the development of the computer models and improving our understanding of the process which allowed us to develop the new manufacturing process.*

IMCRC funding also allowed FormFlow to develop an automatic clamping system which holds the corrugated sheets while the bend is formed, to reduce surface scratching. They noted that the 2D laser system and the FormFlow In-phase Corner would not have been possible in the absence of IMCRCs support.

E.7.2 Economic impacts

Table E.2 shows the results of the Cost Benefit Analysis (CBA) of the project at the 3, 7 and 10 per cent discount rates.

The inputs in Table E.1, adjusted to 2021-22 dollars, have been included as the costs. The benefits include cost savings, additional revenue for Form Flow and customer savings and efficiencies. The 7 per cent rate is the central rate recommended by the Commonwealth Government for best-practice CBA, with the 3 and 10 per cent rates included as a sensitivity test. The results of the CBA show that the net impact is positive at all three discount rates.

At a discount rate of 7 per cent, the Net Present Value (NPV) is expected to be **$12,567,559** over the analysis period (2016-17 to 2029-30), and the BCR is 21.11. An estimated BCR above one suggests that the benefits are expected to outweigh the costs of the project.

Table E.2 NPV of economic impacts of FormFlow project at 3, 7, and 10 per cent discount rates (2021-22 dollars)

	Discount rate 3%	Discount rate 7%	Discount rate 10%
Costs	$611,306	$624,978	$635,232
Benefits	$16,171,670	$13,192,536	$11,413,710
Net Present Value	**$15,560,364**	**$12,567,559**	**$10,778,478**
BCR	**26.45**	**21.11**	**17.97**

Source: data provided by FormFlow to IMCRC

Note that the benefits reported by FormFlow have been adjusted to consider the attribution of benefits to IMCRC, as well as expected costs relating to selling, general and administrative expenses. The analysis period was from 2016-17 to 2029-30

E.7.3 Other impacts

Partnerships and collaborations

FormFlow have reported two partnerships and collaborations as a result of the IMCRC project between 2021-22 and 2022-23. One of these has been an Australian collaboration while one is a further collaboration between FormFlow and Deakin University.

Uptake in technology

FormFlow have reported 3 instances of adopting, trialling, and experimenting with new technology between 2020-21 and 2022-23. The areas of new technology explored were additive manufacturing/3D printing; virtual or augmented reality; sensors and data analytics; and robotics and automation.

Employment impacts

FormFlow expects to employ 1.5 FTE researchers over the period from 2022-23 to 2029-30 as a result of the project. This is equivalent to 12 FTE job-years over the analysis period.

E.8 Potential future impacts

FormFlow was subsequently a recipient of an ARC Linkage Grant. This grant has allowed FormFlow to further explore the fundamental reasons of how these curves and shapes occur during the FormFlow process. This will allow FormFlow to examine opportunities for new corrugation shapes. Forming a 60-degree bend in a corrugated sheet is the latest development from FormFlow. Known as the C60 bend, this product has been produced in a research setting and the technology is currently being further developed.

Lava Blue

F

KEY FINDINGS

$2.9 million in cash invested by IMCRC and industry partners

Queensland Pacific Metals have signed a licencing agreement to use the Lava Blue technology to build a HPA production plant.

$7.9 million of in-kind investment

Up to **150** new jobs are expected to be created by 2030

The project has:

- Demonstrated a technology for manufacturing High Purity Alumina
- Created a facility that can be used for ongoing research

Project aligns with Australian Government's priorities in areas such advanced manufacturing, clean energy and critical minerals

F.1 Case study framework

This case study uses an evaluation framework that ACIL Allen has used to evaluate the impact and value of research done by a large number of research organisations.[34] The results of applying that framework to the Lava Blue case study are summarised in Figure F.1.

[34] The approach is based on that outlined in the CSIRO Impact Evaluation Guide. See https://www.csiro.au/~/media/About/Files/Our-impact-framework/CSIROImpactEvaluationGuide_Nov2015_WEB.pdf?la=en&hash=B351D24FB3CE02CB34FB859F2C34AA3940EE6D1F .

Figure F.1 Lava Blue Case Study – Impact Framework

INPUTS	ACTIVITIES	OUTPUTS	OUTCOMES	IMPACTS
– $10.8 million in-kind and cash funding.	– Research into the monitoring and control of the chemistry for producing HPA – Develop the process for dealing with impurities and reliably achieving the required levels of purity – Design and build the HPA pilot plant	– Successful demonstration of an innovative process for producing 99.99 per cent pure alumina – Journal papers and conference presentations – Patents and IP agreements	– A proven innovative process for manufacturing HPA. – A Heads of Agreement with Queensland Pacific Metals (QPM) to build a commercial scale HPA plant – A facility for ongoing research	– Economic benefits from the planned commercialisation of Lave Blue's technology. – Employment opportunities – A technology that improves access to critical minerals – Ongoing partnerships and collaborations.

F.2 Background

F.2.1 The IMCRC

The IMCRC is an independent and for-impact cooperative research centre with a successful, proven and scalable model for catalysing research and business partnerships that drive transformative commercial outcomes for participating Australian manufacturers. Through collaboration with businesses, research organisations, industry associations, and government they have catalysed and invested research projects to benefit the wider Australian manufacturing sector. To date, IMCRC has successfully co-invested in more than 70 R&D projects in transformative manufacturing research.

The IMCRC provides its support under four programs, namely:

1. Additive Manufacturing Processes – Here IMCRC's support is focussed on research to advance additive systems, develop and use new materials, improve process control, surface engineering, and to integrate creative design.
2. Automated and Assistive Technologies – This program supports R&D to improve the performance and effectiveness of production systems, such as robotics, automated technologies with perception and situation awareness capabilities.
3. High Value Product Development – This is aimed at developing high value products for domestic use and exports such as new electronic devices, diagnostic tools, and implantable materials.
4. Industrial Transformation – This program promotes the transformation of manufacturing through industry education. It provides resources through IMCRC's Futuremap™ platform to help SMEs assess and adopt emerging digital technologies and new business models.

In addition to the above four programs, the IMCRC launched the Activate Program during the pandemic. It was designed to stimulate collaborative investment and provide opportunities for manufacturing SMEs to invest in smaller R&D projects. The program offered manufacturers access to R&D expertise and matched cash funding between $50,000 – $100,000 for shorter-term, industry-led research projects intended to advance manufacturing and digital technologies (Industry 4.0).

F.2.2 Lava Blue and Queensland University of Technology

Lava Blue was founded by a group of people with many years of experience in areas such as renewable energy, sustainability and advanced technologies. The objective of the firm is to produce high value, high purity minerals for the battery industry, via net zero emissions mineral processing, in particular high purity alumina (HPA). HPA is a chemically inert ceramic material with high thermal and electrical resistivity. It is a critical component in the production of high technology products, such as LEDs, electronic displays; semiconductors; sapphire glass and separators for both lithium ion and aluminium batteries.

Lava Blue has acquired a source of kaolin clay that is suitable for the production of HPA. The JORC Measured Resource is 7.6 million tonnes, which contains more than 27 per cent of HPA. HPA is defined as 99.99 per cent (or greater) pure alumina. Commercially available HPA is generally produced from high purity aluminium via an alkoxide route. The science for producing alumina from clay dates back to the 1940's, although the process has not been successfully commercialised in the years since then. The process is a multistage one. It uses hydrochloric acid (HCl) at different concentrations and HCl gas to progressively remove unwanted material from the alumina. Figure F.2 shows some of the stages of the progressive purification process for HPA from low grade kaolin.

In 2018 Lava Blue began working with QUT developing processes at the laboratory level for refining High Purity Alumina (HPA) from the sapphire bearing kaolin clay deposits at Lava Plains in North Queensland. Having successfully produced HPA in a lab environment, Lava Blue needed to validate the process for making HPA from kaolin at the pilot and commercial level and sought support from the IMCRC to do this.

Figure F.2 Stages in the production of HPA

Source: http://lavablue.com.au/high-purity-alumina/

The Lava Blue project was funded under the IMCRC's Program 3 (High Value Product Development).

F.3 Inputs

The total reported cost of the Lava Blue project is $10,809,960. That amount is made up of cash contributions from IMCRC and Lava Blue of $2,909,571 (see Table F.1). Other contributions were:

— $5,055,894 of non-staff in-kind contributions from industry and university partners

— $2,844,500 of in-kind FTE contributions from industry and university partners

Table F.1 Support for the Lava Blue project

Contributor / Type of support	2019/20 ($)	2020/21 ($)	2021/22 ($)	2022/23 ($)	Total ($)
Cash					
IMCRC + Industry	564,006	742,330	1,406,932	196,303	2,909,571
Non-staff in kind					
Industry + University	663,022	1,863,934	2,413,852	115,086	5,055,894
Staff in kind					
Industry + University	825,000	999,500	834,000	186,000	2,844,500
Total	***2,052,028***	***3,605,764***	***4,654,784***	***497,389***	**10,809,965**

Note: Value of the staff in kind input (Industry + University) in the Lava Blue project is the cash equivalent for salaries calculated at Commonwealth determined rates at the establishment of IMCRC.
Source: IMCRC

F.4 Activities

The objective of the Lava Blue project was to better understand the chemistry of the HPA and scale up risks of the HPA manufacturing process in real time. QUT researchers had demonstrated production of HPA from kaolin at the laboratory scale The aim was now to test the process closer to an industrial scale. There are three streams of work involved in the project, namely:

— Research to develop and validate the analytical methods required to better understand the chemistry of the purification process and have the necessary confidence in the purity of the HPA that is produced.
— Using he results of fundamental research to fine tune the process conditions in order to control for the presence of impurities and achieve required levels of purity
— Translate the chemistry learnings into the engineering design of a pilot HPA production plant

The pilot plant is able to process around 250 kg of kaolin clay feedstock to produce around 20 kg of HPA. The expected value add from that processing is considerable. The clay is valued at around $70 per tonnes, whereas the HPA is around $25,000 per tonne.

The construction of the HPA pilot plant will allow the project team to reduce the technical risks associated with scaling up HPA production to a commercial scale. At the pilot plant the team will use in line monitoring, real time process control and machine learning to develop improved process control. This will allow the project team to carry out multiple tests of the chemical processes in parallel rather than only being able to vary one element of the process at a time.

It will also enable the team to develop advanced control systems that will result in a reliable supply of a high-purity product that meets the stringent quality requirements of users. The researchers have also said that there is potential for the results of the project to be extended to processes for extracting other minerals from ores as well as waste material.

F.5 Outputs

The outputs from the IMCRC Lave Blue project are listed below:

— The design, construction and successful operation of a pilot plant facility for the separation of HPA
— The establishment of the Centre for Predictive Research into Specialty Materials" (PRiSM) at the Redlands Research Park.
— A process to accurately control the chemistry needed to produce 99.99 per cent pure alumina from a variety of sources including the aluminium rich waste streams from other mineral processing operations
— Analytical test methods developed to provide confidence around purity levels
— A successful and ongoing collaborative relationship between Lava Blue and QUT that has secured additional funding.
    – the QUT lead researcher for the project noted that:

We have become a family.

Innovation

The project used machine learning to develop an innovative system to monitor and control the chemistry needed to extract high purity HPA from kaolin clay.

Publications

The following publications arose from the Lava Blue project funded by the IMCRC:

— Pepper, Rachel A., Perenlei, Ganchimeg, Martens, Wayde N., & Couperthwaite, Sara J. (2021) *High purity alumina synthesised from iron rich clay through a novel and selective hybrid ammonium alum process*. Hydrometallurgy, 204, Article number: 105728.

— Cameron J. Johnston, Rachel A. Pepper, Wayde N. Martens, Sara Couperthwaite (2022), *Improvement of aluminium extraction from low-grade kaolinite by iron oxide impurities: Role of clay chemistry and morphology*, Minerals Engineering, Volume 176, 107346

The QUT's lead researcher, Dr Sara Couperthwaite, will give a presentation on the production of HPA from iron rich Australian kaolin clay at the 2023 World Mining Congress.

Patents

Two provisional patents have been filed and one more is being prepared.

Licencing and partnership agreements have been signed between Lava Blue and QUT for IP and the operation of the pilot plant with other commercial parties who want to use it to test their ore bodies and how the minerals they contain might be extracted. The commercialisation agreement has resulted in QUT becoming a significant shareholder in Lava Blue and will lead to royalty payments being paid to QUT which will be shared with key researchers.

Awards

In April 2022 Lava Blue and QUT were awarded a $5.24 million grant under the Commonwealth Government's Critical Minerals Accelerator Initiative. The grant will support the development of world-leading processes for refining critical minerals used in the lithium-ion battery supply chain.[35]

In 2022 Lava Blue and QUT were awarded a grant under the Commonwealth Government's ARC Linkages program for a project to develop specialty doped alumina using a novel in-situ process.

F.6 Outcomes

A key outcome of the project was the construction of the pilot plant for the extraction of HPA from kaolin clay (see Figure F.3). The plant enabled the team to successfully demonstrate the science and technology of the chemical process to extract HPA from a range of different feedstock materials. It also showed that there was a clear potential to apply the same approach to the extraction of other critical minerals.

Figure F.3 Lava Blue and QUT pilot plant

Source: Lava Blue

[35] https://www.qut.edu.au/news?id=180976

The market for HPA is growing quickly. Global demand doubled between 2017 and 2021 and is expected to be around between 180,000 and 200,000 tonnes a year by 2027. This growth in demand is driven by policies such as the G20's expected ban on compact fluorescent lights (CFLs) by the end of 2025. This is expected to lead to a compound annual growth rate (CAGR) of over 13 per cent in the demand for LEDs. The growth in demand for batteries as countries seek to decarbonise their economies will also add to the demand for HPA due to its use as the coating in manufacturing of 'ceramic coated separators'. Michael McCann, Managing Director of Lave Blue, noted that:

> *This project allowed us to focus on fundamental research and explore things that have never been done. Because of Lava Blue's licensing model the results have the potential to catalyse a billion-dollar industry in Australia over the next decade.*[36]

Queensland Pacific Metals (QPM) has entered into a licence agreement with Lava Blue regarding use of their proprietary HPA technology in their Townsville Energy Chemicals Hub (TECH) Project. Lava Blue will play an integral role in the HPA section of the TECH Project, including testing, piloting and providing direct support to the engineering consultants commissioned to carry out the Definitive Feasibility Study (DFS) for the HPA plant.[37] QPM Managing Director, Dr Stephen Grocott, stated that:

> *From our Pre-Feasibility Study, it was evident that HPA production is a significant value enhancer for the TECH Project. We are delighted to work with Lava Blue and their partners QUT and Engenium. This joint development significantly advances us with respect to achieving commercial production of HPA at the TECH Project.*[38]

QPM's HPA plant is expected to have the capacity to produce around 4,000 tonnes of HPA per year.

The Queensland Government has recognised the benefits of developing the TECH Project by declaring it to be a "Prescribed Project", which identifies it as a project of state significance and as economically and socially important to a region.[39] Once operational, the TECH Project will be a sustainable, clean and green production facility that will ultimately position QPM as an attractive supplier of key materials used by the electric vehicle and energy storage industries.

QPM plans to import high grade nickel laterite ore to Townsville from New Caledonia for processing at the TECH facility. The firm already has binding offtake agreements in place with LG Energy Solution and POSCO for nickel and cobalt produced and refined at the TECH Project.[40]

Alignment with government strategic priorities

The Lava Blue project has advanced the opportunities for Australia to become a supplier of minerals that are critical for the manufacture of batteries and LEDs. This aligns well with the 2022 Critical Minerals Strategy of the previous government.[41]

It also aligns with the aims of the current government's proposed National Reconstruction Fund. That Fund is expected to invest in areas such as powering Australia, value adding for resources, and advanced manufacturing. One of its goals is to improve sovereign capability in areas such as critical materials.[42]

F.7 Impacts

F.7.1 Role of IMCRC

The IMCRC's support allowed the project team to build a multidisciplinary research team with the range of skills and expertise. This team had skills in areas such as chemistry, physics, chemical and mechanical engineering, mathematics and automation. This allowed them to look at the problem from many different perspectives and enabled them to develop

36 Personal communication.

37 That engineering firm has worked with Lava Blue for several years on the development and construction of Lava Blue's pilot plant.

38 https://www.listcorp.com/asx/qpm/queensland-pacific-metals-limited/news/hpa-technology-license-with-lava-blue-2640909.html

39 https://qpmetals.com.au/tech-project/project-overview/

40 Ibid.

41 https://www.industry.gov.au/publications/critical-minerals-strategy-2022

42 file:///C:/Users/jsoderbaum/Downloads/ECR157_National%20Reconstruction%20Fund%20-%20Australian%20Labor%20Party.pdf

and build a scalable technology that can produce various high purity products in response to the particular needs of different customers.

Without IMCRC's support they would perhaps have been able to understand the chemistry, but they would not have been able to tailor the process to suit the needs of different users. The IMCRC also allowed them to build a bigger pilot plant than other wise been possible.

The QUT's lead researcher, Prof Sara Couperthwaite, noted that:

> *The additional funding provided by IMCRC at the start of the COVID pandemic enabled us to pause upscaling of the process for extracting HPA from a single clay and spend more time to explore the fundamental science in more detail and build the machine learning models that ultimately enabled them to construct a pilot plant that both demonstrated the process for making HPA and also provides a facility for ongoing research.*[43]

In addition the IMCRC was able to provide a connection to a firm (Engenium) with the expertise needed for the design and construction of the pilot plant and other CRC participants with testing facilities not available at QUT.

F.7.2 Economic impacts

Table F.2shows the results of the Cost Benefit Analysis (CBA) of the project at the 3, 7 and 10 per cent discount rates. The inputs in Table F.1, adjusted to 2021-22 dollars, have been included as the costs. The estimated benefits used in the CBA are the preliminary figures that Lava Blue provided to IMCRC.

ACIL Allen believes that the estimate of benefits is likely to be highly conservative. The analysis only examines the benefits that are estimated to flow to Lava Blue. It does not consider the potential future benefits from the proposed QPM plant. That planned plant is expected to produce some 4,000 tonnes of HPA a year, much of which is likely to be exported. That HPA would have a market value of around $100 million.

The seven per cent rate is the discount rate recommended by the Commonwealth Government as best-practice for CBAs. The three and 10 per cent discount rates have been included as sensitivity tests. The results of the CBA show that the net impact is positive at all three discount rates. At a discount rate of seven per cent, the Net Present Value (NPV) is estimated to be over $3.4 million over the analysis period (2016-17 to 2029-30), giving an estimated BCR of 1.29. A BCR above one means that the estimated benefits outweigh the costs of the project.

ACIL Allen believes that a BCR of 1.29 (at a DR of 7 per cent) is a very good outcome for a project such as this. However, as noted above, ACIL Allen believes that this CBA uses very conservative estimates of benefits and if the proposed QPM plant proceeds then the actual BCR could actually be well above 1.29.

Table F.2 NPV of economic impacts of Lava Blue project at 3, 7, and 10 per cent discount rates (2021-22 dollars)

	Discount rate 3%	Discount rate7%	Discount rate 10%
Costs	$11,216,296	$11,525,413	$11,762,583
Benefits	$18,282,323	$14,924,956	$12,938,340
Net impact	**$7,066,028**	**$3,399,543**	**$1,175,757**
BCR	**1.63**	**1.29**	**1.10**

Source: data provided to IMCRC

Note that the benefits reported by Lava Blue have been adjusted to consider the attribution of benefits to IMCRC, as well as expected costs relating to selling, general and administrative expenses. The analysis period was from 2016-17 to 2029-30

[43] Personal communication

F.7.3 Other impacts

Employment impacts

Lave Blue estimates that at least 15 new jobs would be created per 1000 tonnes of annual production capacity. The QPM plant will have a capacity of 4,000 tonnes a year. Negotiations are underway with two other firms to licence the technology, each for a 2,000 tonnes a year plant. The expectation is that there will be 10,000 tonnes of licenced production in operation in Australia by 2030. If so, then some one hundred and fifty new jobs could be created as a result of this project by 2030.

Partnerships and collaborations

Lava Blue expects to have entered into a total of 11 partnerships and collaborations between 2019-20 and 2022-23. They have reported 5 Australian collaborations and 5 Australian partnerships as a result of the IMCRC project between 2019-20 and 2021-22. They expect to enter a new research partnership in 2022/23.

Uptake in technology

Lava Blue have reported 4 instances of adopting, trialling, and experimenting with new technology between 2019-20 and 2021-22. The areas being explored include virtual or augmented reality; advanced materials; sensors and data analytics; and machine learning/artificial intelligence.

F.8 Potential future impacts

The technology developed by this project has many other potential applications. Lava Blue are currently exploring using the technology to:

— Assist a vanadium producer to reduce their waste stream and create co-products
— Produce useful quantities of magnesium, molybdenum and other minerals from mine waste
— Process other materials (such as fly ash) to extract valuable minerals.

Movement Detector System

G

KEY FINDINGS

$4.81m invested by IMCRC and industry partners

$34.15m NPV of present and anticipated economic impacts identified to 2030. BCR of 7.76

The project has produced **a movement detector system**

9 full time equivalent jobs created (rising to 33 by 2027)

2 students trained as a result of the project

Alignment with Government priorities:
National Manufacturing Priorities & Modern Manufacturing Initiative

G.1 Case study framework

This case study uses an evaluation framework that ACIL Allen has used to evaluate the impact and value of research done by a large number of research organisations.[44] The results of applying that framework to the Movement detector System case study are summarised in Figure G.1.

[44] The approach is based on that outlined in the CSIRO Impact Evaluation Guide. See https://www.csiro.au/~/media/About/Files/Our-impact-framework/CSIROImpactEvaluationGuide_Nov2015_WEB.pdf?la=en&hash=B351D24FB3CE02CB34FB859F2C34AA3940EE6D1F .

Figure G.1 Movement Detector System Case Study – Impact Framework Diagram

INPUTS	ACTIVITIES	OUTPUTS	OUTCOMES	IMPACTS
– Investment in research and development by Monitum and QUT – QUT's expertise in Global Navigation Satellite Systems	– Research and development – Design – Prototyping – Advanced manufacturing	– Movement detector components – IoT connectivity to provide real time monitoring – Software to manage the system	– A movement detection system able to detect sub-millimetre movement in three dimensions	– Faster detection of movement – Greater efficiencies in monitoring movement – Reduced risk

Source: ACIL Allen

G.2 Background

G.2.1 The IMCRC

IMCRC is an independent and for-impact cooperative research centre with a successful, proven and scalable model for catalysing research and business partnerships that drives transformative commercial outcomes for participating Australian manufacturers. Through collaboration with businesses, research organisations, industry associations, and government they are able to co-fund, invest and advance research projects and the wider manufacturing sector. To date, IMCRC has successfully co-invested in more than 70 R&D projects in transformative manufacturing research.

The IMCRC provides its support under four programs, namely:

1. Additive Manufacturing Processes – Here IMCRC's support is focussed on research to advance additive systems, develop and use new materials, improve process control, surface engineering, and to integrate creative design.
2. Automated and Assistive Technologies – This program supports R&D to improve the performance and effectiveness of production systems, such as robotics, automated technologies with perception and situation awareness capabilities.
3. High Value Product Development – This is aimed at developing high value products for domestic use and exports such as new electronic devices, diagnostic tools, and implantable materials.
4. Industrial Transformation – This program seeks to promote the transformation of manufacturing through industry education. It provides resources to help SMEs to assess and adopt emerging digital technologies and new business models.

In addition to the above four programs, the IMCRC launched the Activate program during the pandemic.

G.2.2 Monitum/Kurloo and the Queensland University of Technology

Geospatial data is a critical component of every construction project, reducing risk and improving efficiencies. But gathering this data is often costly and labour intensive. Monitum's Managing Director, Lee Hellen, recognised that more affordable, simpler products are needed to enable broader uptake of precise positioning technology.

Monitum partnered with the Queensland University of Technology (QUT) to develop a cost-effective Internet of Things (IoT) solution using low-medium-end Global Navigation Satellite System sensors and low-power wide-area networks. Monitum's Australia-made product makes precise positioning accessible and affordable, with applications across industries such as infrastructure, transport and mining.

Working with QUT, Monitum has created a fully integrated smart device that is supported by a cloud processing and data analytics service. Together, they enable millimetre-precise deformation data to be obtained automatically, remotely and in near real-time. The collective research competence provided by QUT's project team, led by Professor Yanming Feng, has been critical to delivering this innovative outcome.

Closely collaborating with a foresightful business like Monitum enables researchers to focus on technological challenges and achieve the expected outcome. In this instance, we were able to work together as one team, and the project outcome is a testament to the importance of this effective collaboration.

Professor Yanming Feng

Prior expertise that helped inform this project came from QUT researchers working in the CRC for Spatial Information. The successful research contribution from QUT has strengthened the university's credibility within the geospatial sector.

The Movement Detector System project was funded under the IMCRC's Program 3: High Value Product Development Program, Industry 4.0

G.3 Inputs

IMCRC and Monitum provided $1,750,610 in cash and in-kind contributions for this project (see Table G.1).

Other contributors were:

— $947,648 of non-staff in-kind contributions from industry and university partners

— $2,107,500 in-kind FTE contributions from industry and university partners

Table G.1 Financial and in-kind support for the Movement Detector Project

Contributor / Type of support	2018-19 ($)	2019-20 ($)	2020-21 ($)	2021-22 ($)	2022-23 ($)	Totals ($)
Cash						
IMCRC + Industry	22,961	233,147	485,051	905,926	103,525	1,750,610
Non-staff in kind						
Industry + University	9,223	179,473	305,317	380,259	73,376	947,648
Staff in kind						
Industry + University	108,400	224,850	562,250	637,000	575,000	2,107,500
Total	**140,584**	**637,470**	**1,352,618**	**1,923,185**	**751,901**	**4,805,758**

Note: Value of the staff in kind input (Industry + University) into the IMCRC project is the cash equivalent for salaries calculated at Commonwealth determined rates at establishment of IMCRC.

Source: IMCRC

G.4 Activities

The IMCRC project described in this case study has developed an effective IoT solution to automatically measure civil structures using low-medium-end Global Navigation Satellite System (GNSS) sensors. In the first instance the research project focused on the hardware design and advanced manufacturing process to produce low power GNSS IoT sensors. The project team sought to be "first to market", staying ahead of the IoT innovation cycle by offering the latest functionalities to manage the sensors, integrate and process data, and deliver interactive reports and dashboards.

To overcome a gap between IoT sensor and standalone GNSS technology in the market, a four-level IoT reference framework (sensors, networks, service platform and applications) was established to simplify the development, deployment, service and upgrade of each GNSS IoT component. The new GNSS-IoT system has allowed Monitum to develop a new business model that automates the monitoring of structures, reducing the risk and cost in the construction and maintenance of infrastructure assets.

This project has seen partnership with Australian manufacturing companies and service providers. Two prototypes were developed during the project and tested as Minimum Viable Product to establish software and application programming interface A leading geotechnical consultancy, Butler Partners, tested the sensors across three diverse environments and Australian electronics manufacturer, Intellidesign, assisted with the design and production. Throughout the collaboration, Monitum installed and tested the sensor devices across multiple environments including large scale infrastructure for the likes of Port of Brisbane and Queensland Rail.

G.5 Outputs

Outputs from the IMCRC project are:

— A project and business innovation service model has been developed
— A spin-out company, Kurloo Technology Pty Ltd (Kurloo) has been established
— Kurloo provides automated monitoring and analytics for geotechnical and structural performance using GNSS and The Internet of Things
— The Kurloo Nest Platform as an Australia-made product and service[45]
— Machine learning for geotechnical applications will allow predictive behaviours for weather and ground movement events.

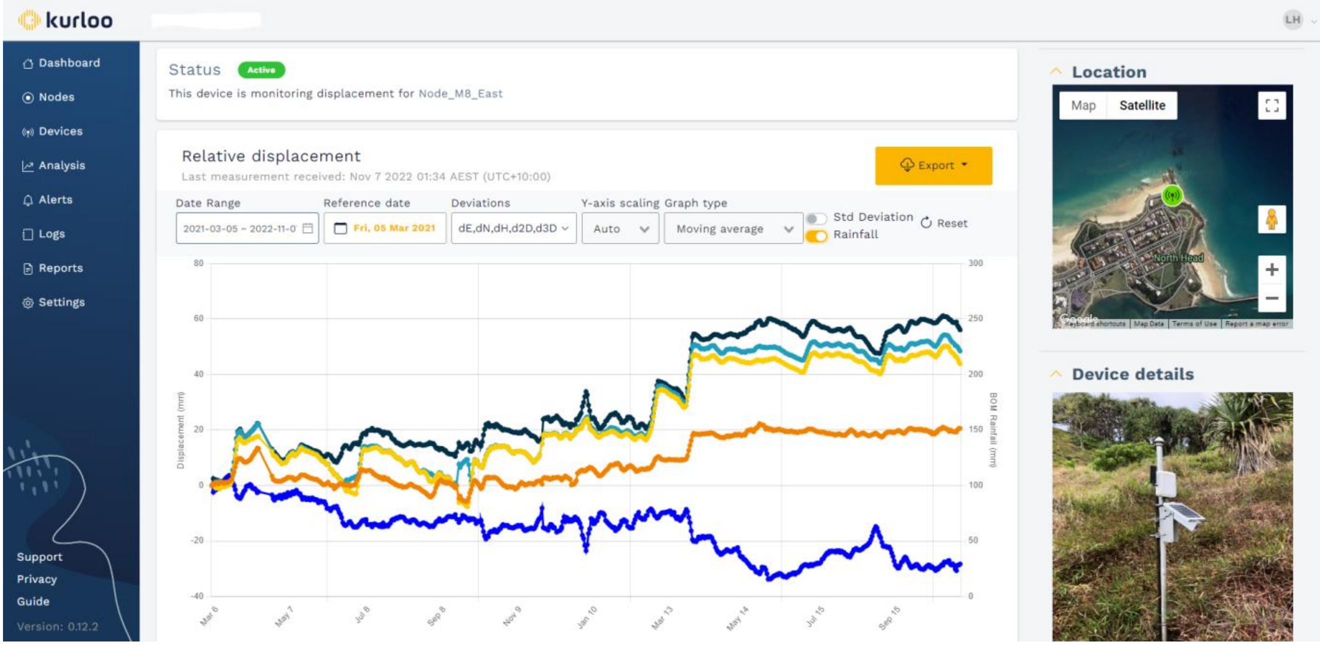
Figure G.2 shows installation examples of the Kurloo device. Figure G.3 below shows a screen capture from the Kurloo Nest Displacement Processing Service which processes the data collected by the Kurloo device.

Figure G.2 Kurloo Device

Source: Kurloo, 2022

[45] Kurloo 2022, accessed on 19 September 2022 at https://kurloo.io

Figure G.3 The Kurloo Nest Displacement Processing Service



Source: Kurloo, 2022

Innovation

This product includes innovations in its hardware, software, product design and use of GNSS sensors.

Intellectual property

To this point number of patents and a design applications are pending

Australian Innovation Patent ID 2018101263- Device, System and Method for Monitoring Settlement and Structural Health

Australian Registered Design ID 202116493 - Sensor Device

Australian Provisional Patent ID 2021904246 - Device and system for monitoring geological and structural displacement

Awards

2022 APSEA – Qld regional award for Small Business Innovation – Port of Brisbane Sea wall project

G.6 Outcomes

Monitum launched its new technology through its spin-off company, Kurloo in June 2022. The products and services that it provides will; save customers time and money. It also reduces risks and improves safety.

It is anticipated that QUT will receive royalty payments arising from its role in this project.

Adoption

Initial customers/users include A variety Australian of Port operators, Dam owners, Energy providers, Mining Companies, Transport Infrastructure and Geotechnical engineering Consultants

Alignment with government strategic priorities

The outcomes of this project align with the Australian National Manufacturing Priorities, in particular, space and resources technology. It also aligns with the Modern Manufacturing Initiative Translation Stream — projects that translate well-developed research into commercial outcomes (new or improved products or manufacturing processes).

G.7 Impacts

The major impacts from this project will be in the form of time and cost savings for customers in construction and infrastructure. Kurloo supports a global push to digital asset management and a need to build more resilient infrastructure for improved project efficiency. By adopting Kurloo, asset owners know precisely how critical assets perform during significant weather events and higher risk activity in near real time. This delivers measurable benefit to the customer though communicating findings more quickly and accurately, supporting improved risk management and maintenance planning . . The service provides faster detection of movement with greater efficiencies and less risk.

The world infrastructure market, where the results of this project could be applied, is very large.

For example, two dam failures illustrate the scale of the problem that the mining industry wants to address:

— The Mariana dam disaster in 2015 killed 19 people and destroyed the village of Bento Rodrigues, Brazil. Three locomotives and 132 wagons were buried. The mud destroyed two sections of railway bridge and about 100 metres of railway track, and

— The Brumadinho dam disaster occurred on 25 January 2019 when a tailings dam at the Córrego do Feijão iron ore mine, near Brumadinho, Minas Gerais, Brazil, suffered a catastrophic failure. The dam released a mudflow that killed 270 people.

G.7.1 Role of IMCRC

IMCRC provided funding and advice, helping to commercialise the product. IMCRC helped the project to identify a manufacturer. IMCRC's business model was a key to supporting the fruitful project, as it incentivised university-industry collaboration and drove co-investment.

> *By championing the project and being a hands-on advisor, IMCRC helped formalise our idea, kept us committed to the innovation, and ensured we were able to reach mutually beneficial outcomes. This enabled us to engage a local Australian manufacturer, giving greater design control and certainty of a local supply chain. (We) can now offers customers a 100 per cent Australian-made product (and) by embracing Industry 4.0 technologies, we've been able to future-proof our business*
>
> *Lee Hellen, Managing Director*

G.7.2 Economic impacts

In the near term, local based manufacturing for the product and services arising from this project are estimated to be 500 units by the end of 2022-23 and four to five thousand units within 3 years.

Table G.2 shows the results of the Cost Benefit Analysis (CBA) of the project at 3, 7 and 10 per cent discount rates.

The inputs in Table G.1, adjusted to 2021-22 dollars, have been included as the costs. The benefits include cost savings, cost, avoidance and additional revenue for Kurloo. The 7 per cent rate is the central rate recommended by the Commonwealth Government for best-practice CBA, with the 3 and 10 per cent rates included as a sensitivity test. The results of the CBA show that the net impact is positive at all three discount rates.

At a discount rate of 7 per cent, the Net Present Value (NPV) is expected to be $34,152,858 over the analysis period (2016-17 to 2029-30), and the BCR is 7.76. A BCR above one suggests that the benefits can be expected to outweigh the costs of the project.

Table G.2 NPV of economic impacts of Movement Detector project at 3, 7, and 10 per cent discount rates (2021-22 dollars)

	Discount rate 3% ($)	Discount rate 7% ($)	Discount rate 10% ($)
Costs	$4,949,759	$5,053,278	$5,134,604
Benefits	$46,433,210	$39,206,136	$34,731,594
Net Present Value	**$41,483,451**	**$34,152,858**	**$29,596,989**
BCR	**9.38**	**7.76**	**6.76**

Source: data provided to IMCRC

Note that the benefits reported by Monitum have been adjusted to consider the attribution of benefits to IMCRC, as well as expected costs relating to selling, general and administrative expenses. The analysis period was from 2016-17 to 2029-30

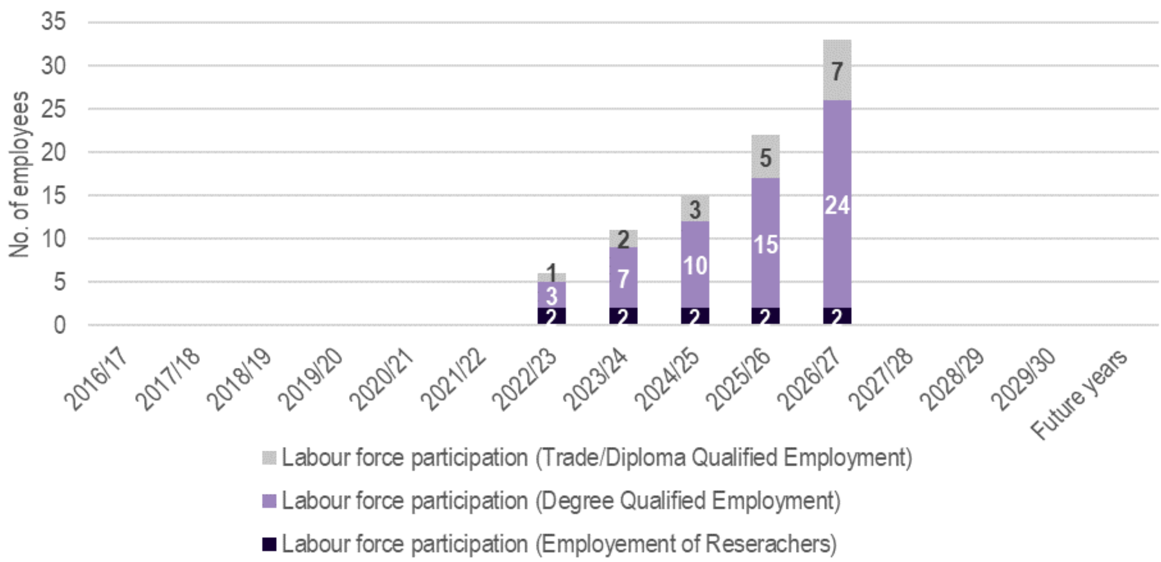
G.7.3 Other impacts

The biggest potential social impacts from this project are avoidance of disasters such as mine tails dam failures and infrastructural collapses.

Employment impacts

The employment impacts will arise from the manufacture of the Kurloo devices and the supply of software enhancements and improvements including machine learning . Kurloo expects to employ six FTE (two researchers, three degree-qualified employees and one Trade/Diploma qualified employee) in 2022-23, which will rise to 33 FTE employees (two researchers, 24 degree-qualified employees, and seven Trade/Diploma qualified employees) by 2026-27 as a result of the project. This is equivalent to 87 FTE job-years over the analysis period.

Figure G.4 Employment by employee category – Monitum/Kurloo



Source: ACIL Allen based on Kurloo data

Total FTE job-years over analysis period = 87

Educational impacts

Monitum/Kurloo expect to two students to complete their studies (PhDs and Masters) through the project between 2018-20 and 2022-23.

Partnerships and collaborations

A total of 12 partnerships and collaborations are expected between 2020-21 and 2023-24. Of these, 10 are Australian collaborations, one is an Australian partnership and one further collaboration planned between Kurloo and the research partner.

Uptake in technology

Kurloo expects to adopt, trial, and experiment with new technology 4 times between 2019-20 and 2022-23. The areas of new technology that have/will be explored are additive manufacturing/3D printing; advanced materials; sensors and data analytics; machine learning/artificial intelligence; and space based communications.

Other

QUT now has a persuasive example in geospatial science to demonstrate its capability, allowing the university to undertake more diversified research in IoT and positioning technologies.

G.8 Potential future impacts

It is anticipated that QUT will continue to collaborate in a research capacity as the company grows in the years ahead.

Boral

H

KEY FINDINGS

$1.7m cash invested by **IMCRC** and **industry partners**

ACIL Allen has estimated that this project had a **positive NPV** and a **BCR greater than one**

$5.2m non-staff and **FTE in-kind** investment

Reduced CO_2 emissions over the analysis period as a result of the project

The project has led to the development of a **durable Lower Carbon Concrete that reduces CO_2 emissions by 40%** compared to conventional concrete

Alignment with Australian Government's **Recycling & Clean Energy** National Manufacturing Priority

H.1 Case study framework

This case study uses an evaluation framework that ACIL Allen has used to evaluate the impact and value of research done by a large number of research organisations.[46] The results of applying that framework to the Boral case study are summarised in Figure H.1.

[46] The approach is based on that outlined in the CSIRO Impact Evaluation Guide. See https://www.csiro.au/~/media/About/Files/Our-impact-framework/CSIROImpactEvaluationGuide_Nov2015_WEB.pdf?la=en&hash=B351D24FB3CE02CB34FB859F2C34AA3940EE6D1F .

Figure H.1 Boral Case Study – Impact Framework Diagram

INPUTS	ACTIVITIES	OUTPUTS	OUTCOMES	IMPACTS
– $6,851,421 of cash and in-kind inputs into the project.	– Boral worked with the UTS Boral Centre to examine: – the effectiveness of manufacturing approaches of lower carbon concrete (**LCC**) – durability properties essential to long-term performance of the LCC – Worked with UTS Business School to conduct a commercialisation study, and UTS DAB for the life cycle analysis of LCC	– Project led to the development of a 70 per cent SCM concrete product that is at a go-to-market position. The concrete is as durable as regular concrete with approximately 40%[47] CO_2 reduction.	– Expected national commercialisation of the 70 percent SCM concrete by Boral. – Boral's LCC strategy is one of the key decarbonation levers in Boral's 2050 Net Zero Plan – Opened opportunities for researchers in industry. – Adoption of the LCC in select major projects.	The full results of ACIL Allen's economic analysis of this project have not been included due to their commercial sensitivity. However, we have found that: – The project is estimated to have a positive net present value and a benefit-cost ratio above one when using 3, 7 and 10 per cent discount rates. – Additional jobs are expected to be created over the analysis period. – CO_2 emissions over the analysis period will be reduced.

H.2 Background

H.2.1 The IMCRC

The IMCRC is an independent and for-impact cooperative research centre with a successful, proven and scalable model for catalysing research and business partnerships that drive transformative commercial outcomes for participating Australian manufacturers. Through collaboration with businesses, research organisations, industry associations, and government they have catalysed and invested research projects to benefit the wider Australian manufacturing sector. To date, IMCRC has successfully co-invested in more than 70 R&D projects in transformative manufacturing research.

The IMCRC provides its support under four programs, namely:

— *Additive Manufacturing Processes* – Here IMCRC's support is focussed on research to advance additive systems, develop and use new materials, improve process control, surface engineering, and to integrate creative design.

— *Automated and Assistive Technologies* – This program supports R&D to improve the performance and effectiveness of production systems, such as robotics, automated technologies with perception and situation awareness capabilities.

— *High Value Product Development* – This is aimed at developing high value products for domestic use and exports such as new electronic devices, diagnostic tools, and implantable materials.

[47] Compared to reference case in the Green Building Council of Australia rating tool – the carbon reduction benefits vary depending on concrete grade and region. The embodied carbon estimates only include Product Stage emissions.

— *Industrial Transformation* – This program promotes the transformation of manufacturing through industry education. It provides resources through IMCRC's futuremap® platform to help SMEs assess and adopt emerging digital technologies and new business models.

In addition to the above four programs, the IMCRC launched the activate program during the pandemic. It was designed to stimulate collaborative investment and provide opportunities for manufacturing SMEs to invest in smaller R&D projects. The program offered manufacturers access to R&D expertise and matched cash funding between $50,000 – $100,000 for shorter-term, industry-led research projects intended to advance manufacturing and digital technologies (Industry 4.0).

H.2.2 Boral and University of Technology Sydney (UTS)

Boral was the industry lead of this project. Boral is the largest integrated construction materials company in Australia, producing and selling a broad range of construction materials including quarry products, cement, concrete, asphalt, and recycled materials. Employing approximately 9000 employees and contractors, Boral's footprint includes some 356 operating sites nationally.[48]

Boral's university partner was UTS. UTS is the top-ranked young university in Australia.[49] UTS aims to advance knowledge and learning through research-inspired teaching, and establishing partnerships with industry, the professions and community. UTS is part of the Australian Technology Network of universities: a group of universities committed to working with industry and government to deliver practical and professional courses. With a total enrolment of over 44,000 students, UTS is one of the largest universities in Australia.[50]

H.3 Inputs

IMCRC and Boral provided $1,666,717 in cash and in-kind contributions for this project (see Table H.1). Other contributors were:

— $1,145,904 of non-staff in-kind contributions from industry and university partners

— $4,038,800 in-kind FTE contributions from industry and university partners

Table H.1 Support for the Boral project

Contributor / Type of support	2020/21	2021/22	2022/23	Total
Cash				
IMCRC + Industry	$613,324	$1,053,393	-	$1,666,717
Non-staff in kind				
Industry + University	$430,162	$715,742	-	$1,145,904
Staff in kind				
Industry + University	$1,915,000	$2,123,800	-	$4,038,800
Total	**$2,958,486**	**$3,892,935**	**-**	**$6,851,421**

Note: Value of the staff in kind input (Industry + University) into the IMCRC project is the cash equivalent for salaries calculated at Commonwealth determined rates at establishment of IMCRC.

Source: IMCRC

H.4 Activities

As a company, Boral aims to reduce its carbon footprint through providing sustainable building and construction solutions. One of these solutions is through its Lower Carbon Concrete (LCC) products, which utilise less Ordinary Portland Cement (**OPC**) than conventional concrete. OPC is the main binder for concrete and is also the second biggest contributor to carbon

48 Refer: https://www.boral.com/about

49 A young university is defined as being established under 50 years ago

50 Refer: https://www.uts.edu.au/about/university/overview

emissions after fossil fuels.[51] Boral has already successfully commercialised a range[52] of LCC concrete products, with some products replacing up to 50 per cent of OPC content with supplementary cementitious materials (SCMs). Examples of SCMs include fly-ash and ground granulated blast-furnace slag (GGBFS), which are waste products from the mining and thermal industries.[53] The focus of this project was to seek to expand Boral's LCC range to include a concrete that replaces 70 per cent of OPC with SCMs.

This project built on Boral and UTS's existing partnership, which began in early 2020. The IMCRC project, which commenced later that year, was the first major project at the newly established UTS Boral Centre for Sustainable Building at UTS Tech Lab, within the School of Civil and Environmental Engineering. To increase the level of SCM from 50 per cent to 70 per cent, the concrete mix, which includes OPC, SCM and Boral's patented GGBFS activator, required reoptimisation. IMCRC funding went towards the equipment and research expertise needed to reoptimise and test the 70 percent SCM concrete.

At the UTS Tech Lab, UTS and Boral examined the effectiveness of the proposed manufacturing approaches for the 70 per cent SCM concrete and tested methods to improve the concrete's surface finishing techniques. This involved looking at the strength and mechanical properties of the concrete and conducting a broad range of tests to achieve the required performance. Once tested by the Lab, the concrete underwent field trials to ensure that it had the durability, pourability and pumpability to be practical for the sector and meet customer requirements. Southern Highlands Concrete Constructions collaborated on the project and participated in test mixing and installation for user feedback.

UTS Faculty of Design, Architecture & Building worked with Boral to evaluate the life cycle analysis and life cycle cost of the new lower carbon concrete highlighting the benefit to both the environment and cost in buildings and infrastructure.

Boral also worked closely with the UTS Business School during this project. The UTS Business school conducted a study to analyse target customers for Boral's LCC and the potential take-up of the product in the construction sector This exercise was supported by IMCRC funding.

H.5 Outputs

The Boral project resulted in the following outputs:

Innovation / commercialisation

The project led to the development of a 70 per cent SMC concrete product that is at a go-to-market position, with internal specifications fully documented. The concrete performs as well if not better than conventional concrete in strength and processing with approximately 40% CO_2 reduction.

Publications

UTS have developed the following publications as a result of the IMCRC project, with three further publications set to release in the near future.

— Brooke Mansell, B., Thomas, P., Li, Y., Tapas, M.J. and Holt, C., "The impact of accelerating admixtures on blended cement hydration for early age strength enhancement", Concrete 2021.

— Tapas, M.J., Fu, J., Thomas, P. and Keyte, L., 'High Early Strength Gain Low-carbon Concrete: A Microstructure Study', Concrete 2021.

— Song, Z., Mortazavi, M., Tapas, M.J., Moghaddam, F. and Sirivivatnanon, V., "Particle packing theory in ultra-sustainable concrete with high SCM content", Concrete 2021.

51 Refer: https://www.imcrc.org/boral_ultra-sustainable_concrete/

52 Boral's lower carbon concrete product range includes ENVISIA®, Envirocrete® and Envirocrete®Plus

53 Refer: https://www.sciencedirect.com/science/article/abs/pii/S095965261600158X

Patents

The project led to extensions of existing IP relating to manufacturing and curing/placement technology of the LCC.

H.6 Outcomes

The project led to the development of a 70 percent SCM concrete. Not only is the commercialisation of this concrete expected to lead to significant economic impacts, but it is also expected to result in significant emissions savings for Boral and its customers. Almost 30 million cubic metres of concrete is used in Australia a year, with Normal Class GP blend concrete producing approximately 270 to 450 kg CO_2/cubic metre of carbon emissions, depending on concrete grade and region among other factors.[54] At 70 per cent SCM, CO_2 emissions are reduced by approximately 40 per cent compared to conventional concrete (up to 10 per cent additional saving compared to 50 per cent SCM concrete).

In 2021, during the IMCRC project, Boral set one of the highest carbon emissions reduction targets in the global construction materials industry[55], and joined the Science Based Targets initiative (SBTi) Business Ambition for 1.5°C and UNFCCC Race to Zero. Boral's Lower Carbon Concrete strategy is one of the key decarbonation levers in Boral's 2050 Net Zero Plan.[56] During consultation, Boral noted that reducing carbon emissions was one of the outputs it was looking for through the project. Many major builders are setting net zero emissions targets by 2050, and Boral expects that its LCC will form part of this transition.

Benefits have also been reported for the researchers involved in the project. When consulted, Professor Vute Sirivivatnanon from the UTS School of Civil and Environmental Engineering noted that researchers have been exposed to and gained valuable experiences in commercial product development through the IMCRC project. A number of researchers have ongoing roles at the UTS-Boral Centre, while a number of others have accepted positions within Boral.

Boral's 70 per cent SCM concrete is currently being utilised in select major projects.

Alignment with government strategic priorities

The IMCRC project aligns with the Australian Government's Recycling & Clean Energy National Manufacturing Priority. Not only did the project result in the development of a LCC which reduces CO_2 emissions , but the SCMs which are part of the concrete manufacturing process are derived from waste materials from the mining and thermal sectors.

H.7 Impacts

H.7.1 Role of IMCRC

Although Boral and UTS had an existing relationship prior to this project, Ali Nezhad (Boral) and Jason Chandler (Boral) stated that the IMCRC project strengthened the UTS-Boral partnership significantly. Ali explained that in the absence of IMCRC, Boral would have relied more heavily on internal capabilities. However, this would not have provided Boral with the same access to the scientific understanding as the IMCRC project:

> *From collaboration point of view, IMCRC extended the partnership beyond the scope initially imagined. That extended partnership is continuing today (Ali Nezhad, August 2022 consultation)*

Not only did it strengthen the collaboration between Boral and the School of Civil and Environmental Engineering, but also with the UTS Business School, which is continuing in other Boral projects:

> *There are new projects that UTS Business School is getting involved in that would not have happened without IMCRC. (Ali Nezhad, August 2022 consultation)*

Ali, Jason and Vute also noted that IMCRC were a fantastic organisation to work with. Ali enjoyed working with IMCRC because it was practical from the beginning of the project, and transparent about processes and how the collaboration was

[54] Reported by Boral during consultation – indicative values only. The embodied carbon varies depending on concrete grade and region.

[55] https://www.boral.com/community-sustainability/net-zero

[56] Ibid.

going to work. Ali noted this work style was very important to Boral and contributed to the success of the collaboration. Ali and Jason considered the project a great demonstration of collaboration between Boral and the university sector

Economic impacts

Economic benefits of the Boral project were estimated through a cost-benefit analysis at the 3, 7 and 10 per cent discount rates over the analysis period (2016-17 to 2029-30). Although the figures cannot be reported due to their commercial sensitivity, ACIL Allen found that the net present value was positive, and the benefit-cost ratio was above one at all three discount rates.

H.7.2 Other impacts

Boral expects that the IMCRC project will lead to CO_2 savings and the creation of additional jobs over the analysis period.

Melbourne
Suite 4, Level 19; North Tower
80 Collins Street
Melbourne VIC 3000 Australia
+61 3 8650 6000

Sydney
Suite 603, Level 6
309 Kent Street
Sydney NSW 2000 Australia
+61 2 8272 5100

Brisbane
Level 15, 127 Creek Street
Brisbane QLD 4000 Australia
+61 7 3009 8700

Canberra
Level 6, 54 Marcus Clarke Street
Canberra ACT 2601 Australia
+61 2 6103 8200

Perth
Level 12, 28 The Esplanade
Perth WA 6000 Australia
+61 8 9449 9600

Adelaide
167 Flinders Street
Adelaide SA 5000 Australia
+61 8 8122 4965

ACIL Allen Pty Ltd
ABN 68 102 652 148

acilallen.com.au