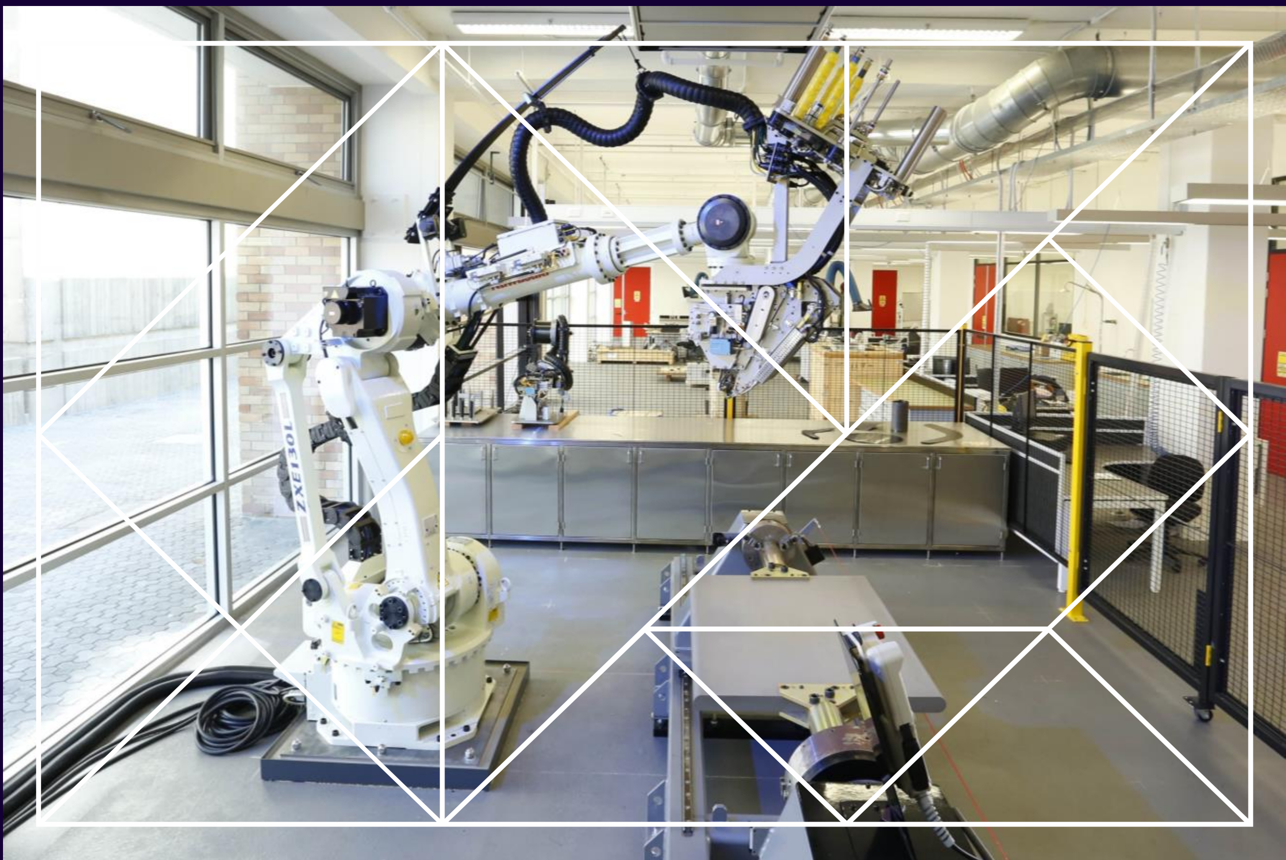
15 July 2024
Report to ARC Training Centre for Automated Manufacture of Advanced Composites

# ARC Training Centre for Automated Manufacture of Advanced Composites

## Highlights and Achievements Report



## About ACIL Allen

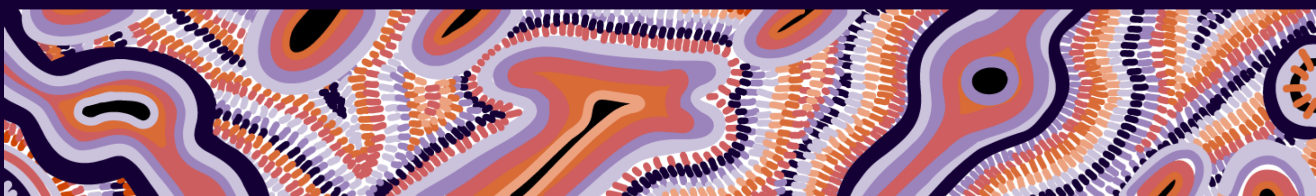
ACIL Allen is a leading independent economics, policy and strategy advisory firm, dedicated to helping clients solve complex issues.

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

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# Glossary

| | |
|---|---|
| ACM CRC | Australian Composites Manufacturing Cooperative Research Centre |
| AFP | Automated Fibre Placement |
| AMAC | ARC Training Centre for Automated Manufacture of Advanced Composites |
| ANU | Australian National University |
| ARC | Australian Research Council |
| ATP | Automated Tape Placement |
| AUD | Australian dollars |
| BCR | Benefit-cost ratio |
| CAGR | Compound Annual Growth Rate |
| CBA | Cost-benefit analysis |
| CF/PA | Carbon-fibre/polyamide |
| CF-PEEK | Carbon-fibre reinforced polyether ether ketone |
| CNTs | Carbon Nano Tubes |
| CRA | Cooperative Research Australia |
| CRC | Cooperative Research Centre |
| CSIRO | The Commonwealth Scientific and Industrial Research Organisation |
| DIN | Defence Innovation Network |
| DSTG | Defence Science and Technology Group |
| EU | European Union |
| GHG | Greenhouse Gas |
| ITRP | Industrial Transformation Research Program |

| | |
|---|---|
| IP | Intellectual Property |
| OEMs | Original Equipment Manufacturers |
| MFC | Macro fibre composite |
| NPV | Net present value |
| NSW | New South Wales |
| PhD | Doctor of Philosophy (the highest possible academic degree a student can obtain) |
| PV | Present value |
| R&D | Research and Development |
| RAN | Royal Australian Navy |
| SBFEM | Scaled boundary finite element method |
| SHM | Structural health monitoring |
| SoMAC CRC | Sovereign Manufacturing Automation for Composites Cooperative Research Centre |
| TCW | Thermoset Composite Welding |
| TfNSW | Transport for NSW |
| TUM | Technical University of Munich |
| UNSW | University of New South Wales |
| US | United States |
| USD | United States dollars |
| WHO | World Health Organization |
| $M | Millions of dollars |

# AMAC's pathway to generating impact

| | |
|---|---|
| **61** Funded projects | Collaborations/ partnerships **52** |
| **23** PhDs trained | Research staff **24** |
| **109** Journal publications | Patents **3** |
| **35** Conference papers | Spin-off companies **3** |

**Total funding**
**$8.02 million**
**($3.85 million from ARC for 2017-22 and $4.17 million from other sources)**

AMAC enabled the **ACM CRC**, a **$250 million** project set for 2023 to 2033 with **30+ industry partners**

## Outcomes

- Knowledge creation
- Enabling research
- Skills development, attraction and retention
- Reduction of barriers to composite manufacturing
- Higher throughput and quality in automated manufacturing
- Reduced cost of production

## Impacts

- Improved productivity and economic activity
- Environmental benefits
- Human capital (skills) formation
- Improved health outcomes
- Improved social outcomes
- Accelerated adoption of new technologies, products, processes and practices

## The **4 AMAC case studies** provide a lower bound estimate of AMAC's total impact

### Estimated impacts (commercialised research)

**DENTAL COMPOSITES PROJECT**

**$21 million net benefits (BCR 7.9)** attributable to AMAC's research for the commercialisation of **Stela**, a mercury-free, self-curing dental filling material.

**COMPOSITE TANKER PROJECT**

**$3 million net benefits (BCR 9.0)** attributable to AMAC's research for the commercialisation of researched techniques and industry partner's **expansion to US market.**

### Potential future impacts (not yet commercialised research)

**COMPOSITE PROPELLER PROJECT**

**$5 million net benefits (BCR 3.4)** attributable to AMAC's research if **fuel and maintenance saving** propeller blades are commercialised.

**BRIDGE MONITORING PROJECT**

**Postponed structural intervention, extended service life and prevention of fatigue cracks** for steel rivetted bridges attributable to AMAC's research if real-time structural health monitoring is adopted.

# Executive summary

ACIL Allen has been engaged by the Australian Research Council (ARC) Training Centre for Automated Manufacture of Advanced Composites (AMAC or the Centre) to develop a Highlights and Achievements Report to assess the impacts of the Centre over its funding period (2017-2022) and to communicate the significant benefits that are possible through collaborative research and training.

This engagement focuses on the impacts of the following 4 research projects through case studies:

— dental composites research undertaken with SDI Limited

— composite tanker research undertaken with Omni Tanker

— composite propeller blade research undertaken with the Defence Science and Technology Group

— bridge Structural Health Monitoring (SHM) research undertaken with Transport for NSW.

To articulate how AMAC created value and frame an evaluation of its impact, ACIL Allen has used an impact pathway to assess these 4 research projects. This impact pathway shows how AMAC's inputs and activities directly or indirectly influence research outputs and outcomes, which generate impacts on the broader community. Analysis of the Centre and these research projects demonstrated the significant impact of AMAC's research. These included both quantifiable and unquantifiable impacts such as:

— *Economic impacts:* commercialisation of SDI Limited's Stela dental composite, and commercialisation of 3 of the 4 research projects undertaken with Omni Tanker have resulted in increased revenues for these partners. There are likely to be future economic impacts if the composite propeller blade research becomes commercialised, which would result in more fuel-efficient vessels in operation, and if the bridge SHM research becomes commercialised, which would result in potential cost savings for monitoring riveted steel bridges in NSW.

— *Research capability and capacity building:* contribution to the stock of knowledge and the longer-term research capability in composites manufacturing of Australia are core purposes of the Centre. This evaluation found that AMAC has improved research capacity by enabling new research directions, research training (e.g. researchers and graduates) and new partnerships (in Australia and internationally), which in turn leads to improved understanding and new knowledge. In particular, 23 PhD students were trained by AMAC which exceeds the initial expectation of 8 PhD students trained under the ARC grant agreement. Furthermore, the addition of 24 research associates across various projects and 10 visiting research staff has exceeded the expected 5 research associates. Many former AMAC PhD students have transitioned from the Centre to work for industry. AMAC's projects align with Australia's National Manufacturing Priorities, for example in the areas of Defence through the composite propeller blade project, and Medical Products through the dental composite project.

— *Environmental impacts:* the dental composite developed in collaboration with SDI created a safer alternative to hazardous mercury-based amalgams, which can cause significant harms to human health and the environment. Repair procedures developed at Omni Tanker will reduce waste by extending the life of their road tankers, and if commercialised, the composite propeller blades could reduce GHG emissions from reduced fuel use.
— *Contribution to knowledge:* surpassing the initial goal of 50 publications, AMAC has achieved 109 publications in Q1 journals (the top 25% of ranked journals), one book chapter, 35 international conference papers, and delivered 14 invited/plenary/keynote talks. AMAC has also received multiple awards which recognise their significant contribution to knowledge.
— *Leveraging of additional investment:* over the period from 2017 to 2022, AMAC received $3.85 million in grant funding from the ARC. During the same period, AMAC successfully attracted $4.17 million in additional investment. This means that, for every dollar that AMAC received from the ARC, the Centre attracted $1.08 in additional investment from other sources.
— *Establishment of ACM CRC:* the success of AMAC played a pivotal role in forming a consortium, led by AMAC Director Professor Gangadhara Prusty, that successfully bid for the Sovereign Manufacturing Automation of Composites Cooperative Research Centre (SoMAC CRC). The CRC is now funded by the Commonwealth of Australia and was renamed the Australian Composites Manufacturing Cooperative Research Centre (ACM CRC). This ambitious $250 million project, set to span from 2023 to 2033, is designed to transform the Australian composites industry by promoting manufacturing automation across more than 30 partnering organisations.

ACIL Allen also conducted a survey of former AMAC PhD students and post-doctoral staff to capture the Centre's contribution to building research capacity and capability in composite manufacturing and understand how AMAC has impacted these individuals' career journeys. The survey of 30 respondents received overwhelmingly positive feedback and found that:

— 87% of respondents believed the training through AMAC was very good or excellent
— 93% of respondents believed the training was relevant to their current work
— 97% of respondents believed the AMAC training was important for the realisation of their achievements at work
— 43% of respondents believed that they would not have received the same training through another avenue
— 97% of respondents would recommend AMAC training to others.

## Estimated impacts

ACIL Allen conducted an indicative cost-benefit analysis (CBA) for 3 of the 4 research projects to estimate the potential and delivered economic benefits that have or could be attributed to AMAC's research. The results of this analysis are presented in Table ES 1 (all impacts have been adjusted for attribution to AMAC). This provides a lower bound, conservative estimate of the returns generated by the investment in the Centre's entire research portfolio.

It is important to note that the dental composites and composite tanker CBAs are based on research that has been commercialised (i.e. implemented into the industry partner's business as a product or process), while the research conducted for the composite propeller blade project has not been commercialised. The impact of the composite propeller blade project is therefore speculative and has been developed to provide an illustrative example of the *potential* impacts if the research was implemented.

As shown in Table ES 1, in all research projects analysed, the Net Present Value (NPV) is above zero and the Benefit Cost Ratio (BCR) is above one. This means that the benefit of all projects has outweighed or are likely to outweigh the costs, which will deliver a net benefit to Australia. To put the scale of the benefits in perspective, the benefits enabled by AMAC through the dental composite research alone ($21 million in net benefits), more than double the total costs of all other research undertaken at AMAC (i.e. is enough to cover both the ARC grant and the funding leveraged from other sources, a total of $8 million).

**Table ES 1** CBA summaries of the 4 research projects (central 7% discount rate, $2023)

| Project title | Research status | PV Costs ($M) | PV Benefits ($M) | NPV ($M) | BCR |
|---|---|---|---|---|---|
| **Dental composites** | Commercialised | $3.0 | $23.9 | **$20.9** | **7.9** |
| **Composite tanker** | Commercialised | $0.3 | $3.0 | **$2.7** | **9.0** |
| **Composite propeller blade** | Not commercialised – illustrative CBA | $1.8 | $6.1 | **$4.3** | **3.4** |

*Source: ACIL Allen*

## Conclusion

The impacts identified and the results of the training survey and project CBAs demonstrate the significant benefits delivered through AMAC's collaborative research and training. The strength of the relationships that AMAC has created is a testament to the Centre's dedication to advancing composite research in Australia and developing the next generation of innovators in this industry. The impacts of AMAC's research will extend beyond the Centre's funding period, which is already evident from its involvement in the commercialisation of research, the significant number of publications and PhDs developed and trained, and the emergence of the ACM CRC. The strong relationships built through the Centre will likely enable the realisation of future impacts for the University of New South Wales (UNSW), the ACM CRC and AMAC's partners.

# 1 This study

ACIL Allen has been engaged by the Australian Research Council (ARC) Training Centre for Automated Manufacture of Advanced Composites (AMAC or the Centre) to develop a Highlights and Achievements Report to assess the impacts of the Centre and to communicate to others in industry and the research community the significant benefits that are possible through collaborative research and training.

This engagement focuses on quantifying (to the extent possible given data availability and confidentiality considerations) the direct impacts of 3 key research projects undertaken by AMAC. This provides a lower bound, conservative estimate of the returns generated by the investment in the Centre's entire research portfolio. The 3 research projects are:

— dental composites research undertaken with SDI Limited
— composite propeller blade research undertaken with Defence Science and Technology Group
— composite tanker research undertaken with Omni Tanker.

In addition, this study qualitatively analyses the non-quantifiable economic, social and environmental impacts delivered by the AMAC, as well as the significant impact of the PhD and researcher training undertaken by the Centre.

A purely qualitative assessment was undertaken for a fourth research project, which was the Bridge Structural Health Monitoring research undertaken with TfNSW.

The structure of the report is provided below:

— **Infographic and Executive Summary**: provides an overview of the study and its findings
— **Chapter 1 (this chapter):** Provides context on this engagement
— **Chapter 2:** Outlines AMAC'S role and objectives
— **Chapter 3:** Discusses how AMAC generates impact
— **Chapter 4:** Provides an overview of the approach to the analysis
— **Chapter 5:** Dental composites research project case study
— **Chapter 6:** Composite tanker research project case study
— **Chapter 7:** Composite propeller blade research project case study
— **Chapter 8:** Bridge monitoring research project case study
— **Chapter 9:** PhD and researcher survey results
— **Chapter 10:** Conclusion.

# 2 AMAC: An overview

AMAC was established in 2017 under the ARC's Industrial Transformation Research Program (ITRP). The Centre received $3.85 million in funding over five years (to 31 December 2022) through the ARC Industrial Transformation Training Centres scheme[1,2], which supports research collaborations between universities and industry to solve complex real-world problems in priority areas for Australia.

AMAC was led by UNSW and was a collaboration between the Australian National University (ANU), the Technical University of Munich (TUM) and nine industry partners.[3]

The Centre's objectives were to:

— promote integrated innovation in automated composite manufacturing, from material design to product realisation

— incorporate key Australian composites innovations into the automated manufacturing process chain

— train a generation of composite manufacturing innovators at the frontier of industry-focused research

— foster strong collaborations between Australian universities and a host of global organisations which vertically span the composites sector from national research providers to large Original Equipment Manufacturers (OEMs)

— drive growth and productivity in the sector by strategically targeting the translation of commercialisable Intellectual Property (IP)

— achieve criticality in advanced composite manufacturing research for a long-term shift in Australia's Research and Development (R&D) capability in the field.

To achieve these objectives, AMAC featured world-class facilities for composite material design, analysis, lay-up, curing and testing. The centrepiece of the Centre was the Automated Fibre Placement (AFP) facility (the only one of its kind in the southern hemisphere), which allowed users to undertake complex shape manufacturing using AFP techniques, manufacture metal-composite hybrids and undertake impact and damage assessments of composites using smart materials and sensors to inform and enhance future designs.

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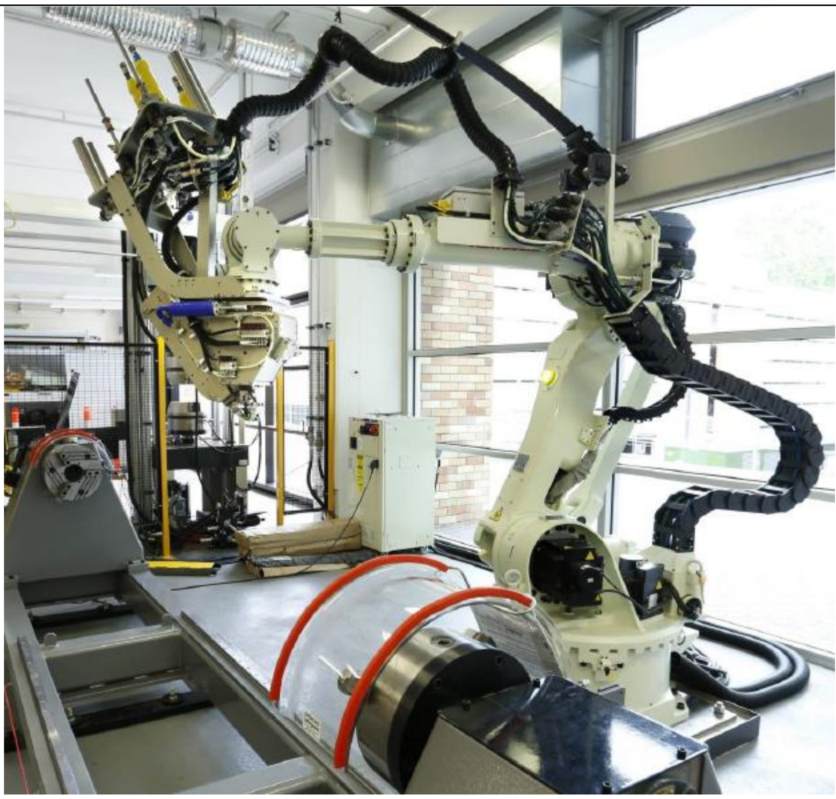
[1] Australian Research Council. (2017). New ARC Training Centre to transform Australia's high-performance carbon composites manufacturing industry. https://www.arc.gov.au/news-publications/media/media-releases/new-arc-training-centre-transform-australias-high-performance-carbon-composites-manufacturing

[2]Australian Research Council. (n.d.). IC160100040 — The University of New South Wales. https://dataportal.arc.gov.au/NCGP/Web/Grant/Grant/IC160100040

[3] The 9 industry partners are: the Ford Motor Company, Omni Tankers, Advanced Composite Structures Australia, Australian Institute of Sports, Carbonix, AFPT, FEI, the Australian Nuclear Science and Technology Organisation (ANSTO), and the Defence Science and Technology Group (DST-G). Source: AMAC, unknown, *Who are we?,* accessed online on 1/03/24 at: https://advanced-composites.co/

**Figure 2.1** AMAC's Automated Fibre Placement facility located at UNSW

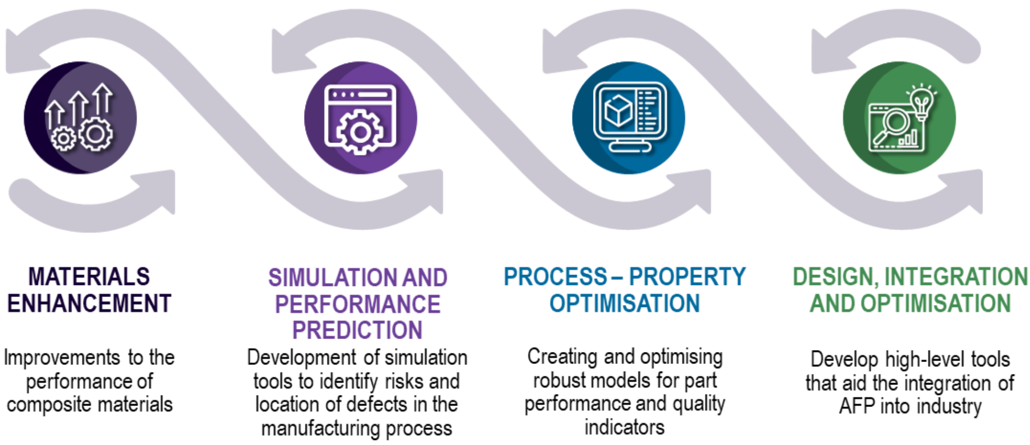


*Source: AMAC Annual Research Report 2021*

Over its 5 years of operation, AMAC helped to enhance the performance of Australia's carbon composites manufacturing industry. It achieved this through market-driven research on composite products and processes undertaken in collaboration with industry and university partners. In addition to the significant commercial impacts generated by AMAC, the Centre has had a profound impact on the PhD students and researchers trained within its collaborative research environment.

During its operation, AMAC produced a range of research across 4 key areas (see Figure 2.2). These 4 areas of research are discussed in more detail below.

**Figure 2.2** AMAC's key work areas




*Source: ACIL Allen based on AMAC's information.*

## 2.1 Materials enhancement

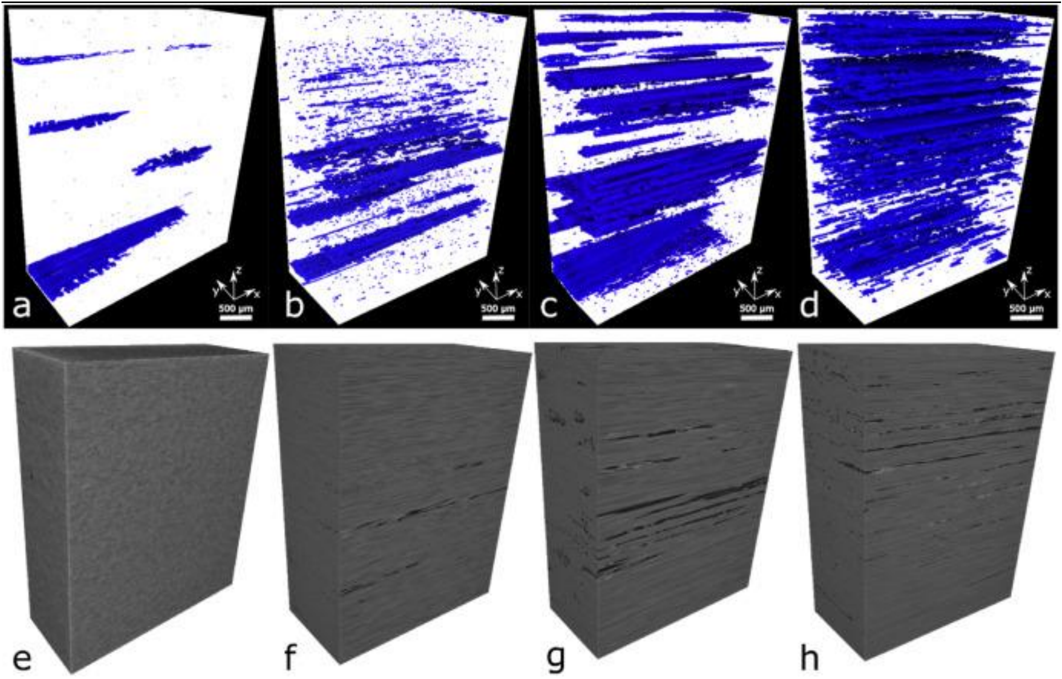
This research area aimed to improve the performance of composite materials. Improvements to the performance of composite materials cascade through to more capable and higher-value products. By helping develop new-generation low-cost materials, AMAC contributed to increase the competitiveness of composites in key industries.

Two examples of research in this area included the following projects:

— Graphene-enhanced prepreg tapes for thermal and electrical conductivity (Figure 2.3 shows 3D visualisations of materials developed during this project)

— Durable nano-scale surface treatments to improve wear and environmental resistance.

**Figure 2.3** 3D visualisations of carbon-fibre/polyether ether ketone composite laminates

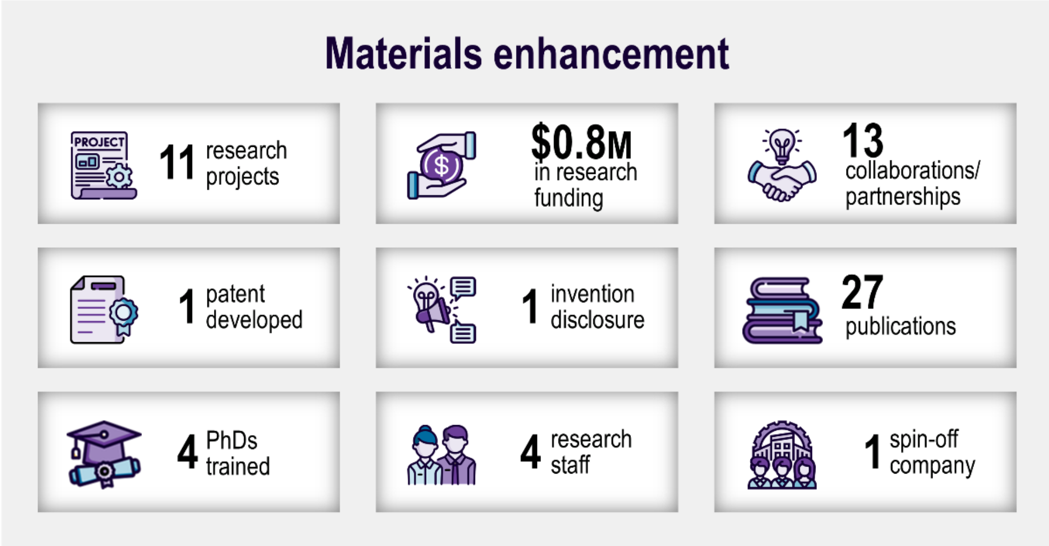



*Source: Leow C et al. (2023). Electrical and thermal conductivity in graphene-enhanced carbon-fibre/PEEK: The effect of interlayer loading. https://www.sciencedirect.com/science/article/pii/S000862232300708X.*

Further details on these projects are provided in Section A.1 in Appendix A. Through these projects, AMAC identified key opportunities to integrate carbon nanotubes (CNTs) and graphene (which have extraordinary potential to change the electrical, thermal and mechanical properties of composites) into the manufacturing chain.

An overview of AMAC's key achievements in this research area is provided in Figure 2.4.

**Figure 2.4** AMAC's key achievements in the materials enhancement research area

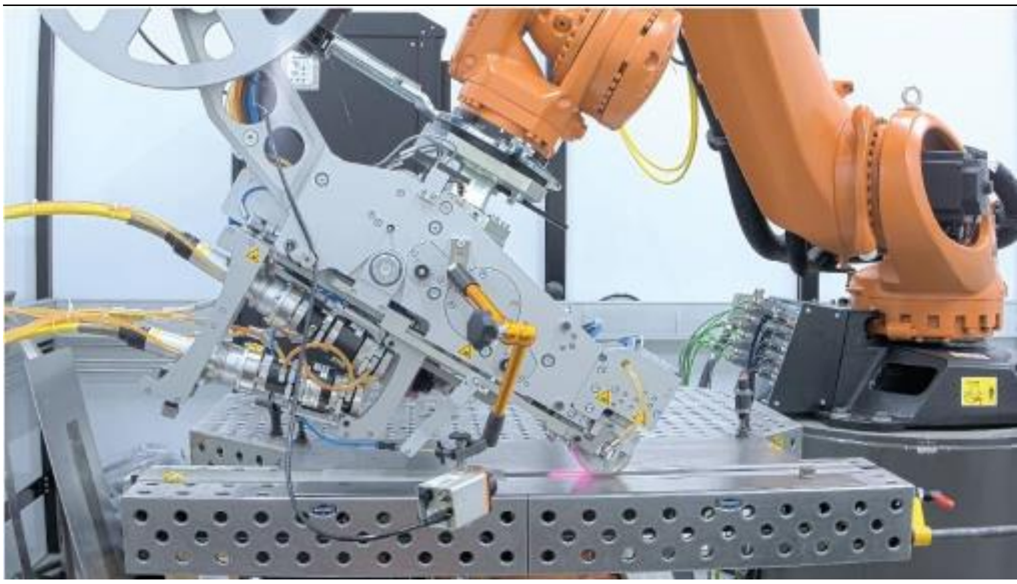



*Source: ACIL Allen based on AMAC's information.*

## 2.2 Process-property optimisation

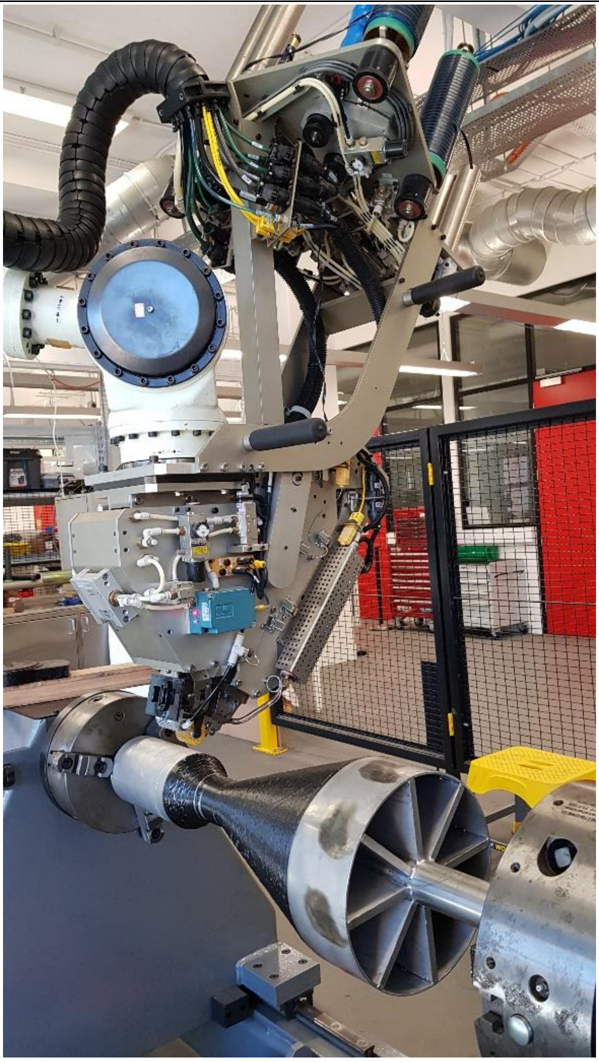
The quality of parts produced in the composite product manufacturing industry is affected by the mechanics of adding material to a mould (e.g. consolidation pressure, consolidation temperature, tape lay down rate and tape distortion). This research area aimed at investigating the potential for enhanced process and quality control systems for automated manufacture that would enable enhanced production quality. In particular, projects in this area sought to create and optimise robust models for part performance and quality indicators by specifically addressing the complex thermal and mechanical environment at the point of material application onto the mould. A dual-laser automated tape placement cell commissioned at ANU (see Figure 2.5) and UNSW's automated fibre placement cell (see Figure 2.6).

**Figure 2.5** Dual-laser automated tape placement cell commissioned at ANU for process-property optimisation research



*Source: AMAC Annual Research Report 2021*

**Figure 2.6** Automated fibre placement cell at UNSW



*Source: AMAC*

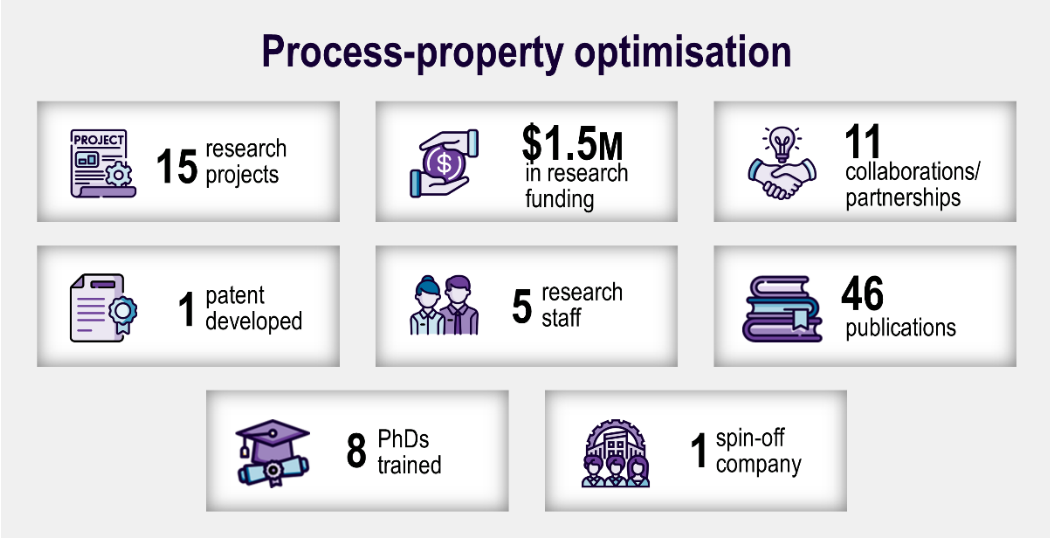
Examples of research in this area included the following projects:

- Smart Composites-Integration of Sensing and Actuating Elements
- Thermoplastic AFP optimisation for metallic bonding
- Post-forming of thermoplastic AFP composite tubes.

Further details on these projects are provided in Section A.2 in Appendix A. Through these projects, AMAC identified opportunities to optimise the process parameters for multi-material interfaces, such as thermoplastic/thermoset or composite/alloy, which helped unlock new opportunities for industry.

An overview of AMAC's key achievements in this research area is provided in Figure 2.7.

**Figure 2.7** AMAC's key achievements in the process-property optimisation research area



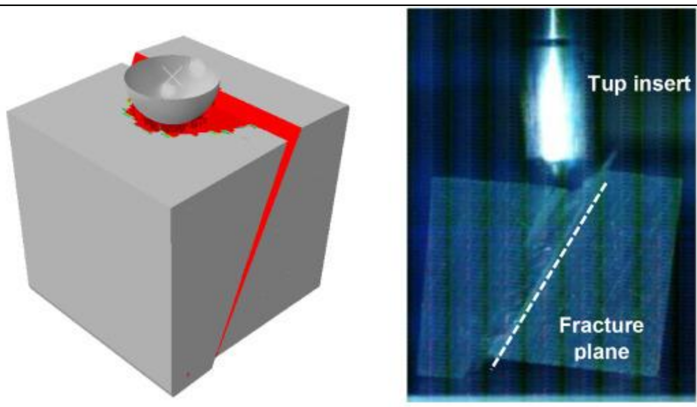

*Source: ACIL Allen based on AMAC's information.*

## 2.3 Simulation and performance prediction

This research area focused on the development of simulation and performance prediction technologies for composite materials. In particular, research focused on developing simulation tools to:

— identify risks in the manufacturing process
— identify likely defect locations (see Figure 2.8)
— predict the as-manufactured properties
— predict the stiffness and strength of manufactured components.

**Figure 2.8** Prediction of specimen fracture under an impact velocity of 7.5 m/s




*Source: AMAC*

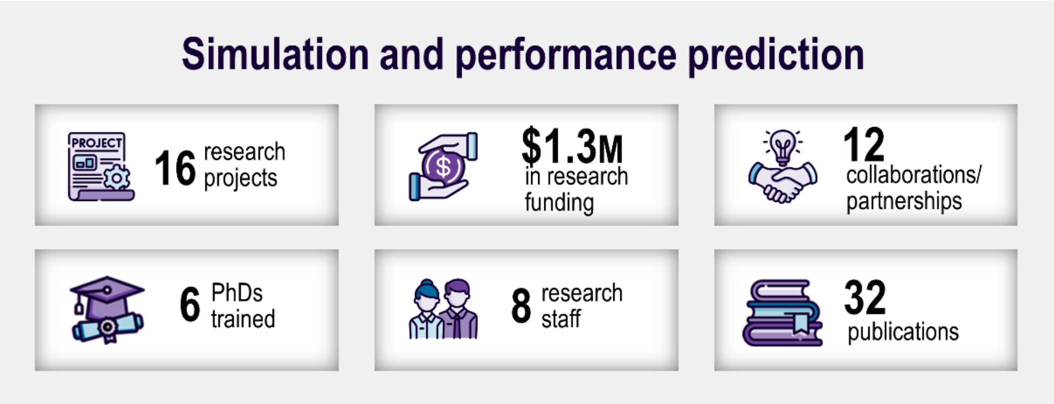
Examples of research in this area included the following projects:

— Bend-twist coupling behaviour through fibre steering
— Implementing cohesive elements in scaled boundary finite element for predicting delamination
— Design and development of composite conveyor support structures for mining environment.

Further details on these projects are provided in Section A.3 in Appendix A. Outcomes from these research projects can lead to higher adoption of composites from better predictability of performance in the manufacturing sector.

An overview of AMAC's key achievements in this research area is provided in Figure 2.9.

**Figure 2.9** AMAC's key achievements in the simulation and performance prediction research area




*Source: ACIL Allen based on AMAC's information.*

## 2.4 Design, integration and optimisation

One of the major obstacles to automated manufacturing of composites, and composite manufacturing in general, is the complexity of design, qualification, manufacture and testing. Automated manufacturing adds additional complexity to this system which imposes unacceptable risks for many businesses. This research theme aims to develop high-level tools (e.g. software, and guidelines) that supported the integration of AFP specifically into industry and commercial applications.

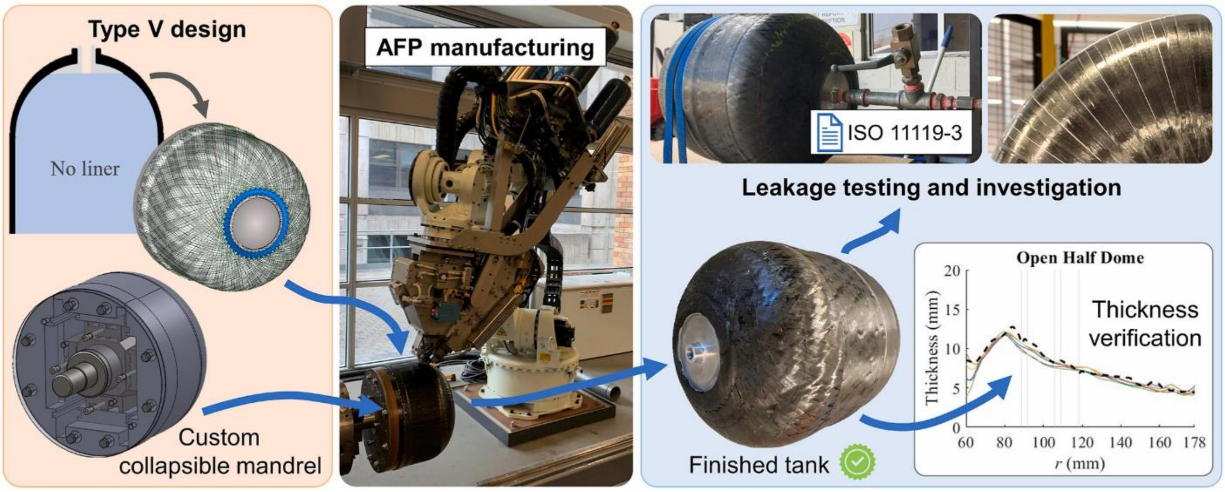
Examples of research in this area included the following projects:

— Manufacture of Composite Wheel for the automotive industry (where a lightweight composite wheel was designed and manufactured

— Automated Manufacture of Adaptive Composite Propellers

— Manufacture of Type V Hydrogen Storage tanks (see Figure 2.10).

**Figure 2.10** Design and manufacture of a Type V composite pressure vessel using automated fibre placement

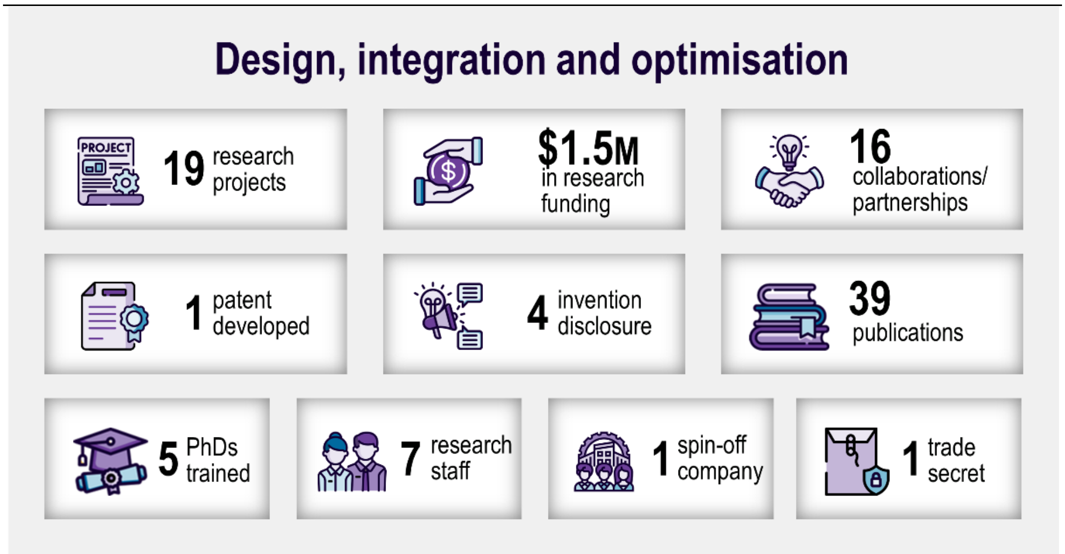



*Source: Air A et al. (2023). Design and manufacture of a Type V composite pressure vessel using automated fibre placement. https://www.sciencedirect.com/science/article/pii/S1359836823005309*

Further details on these projects are provided in Section A.4 in Appendix A. Outcomes from these research projects can lead to AFP being adopted by industry and commercialised at a higher rate.

An overview of AMAC's key achievements in this research area is provided in Figure 2.11.

**Figure 2.11** AMAC's key achievements in the design, integration and optimisation research area




*Source: ACIL Allen based on AMAC's information.*

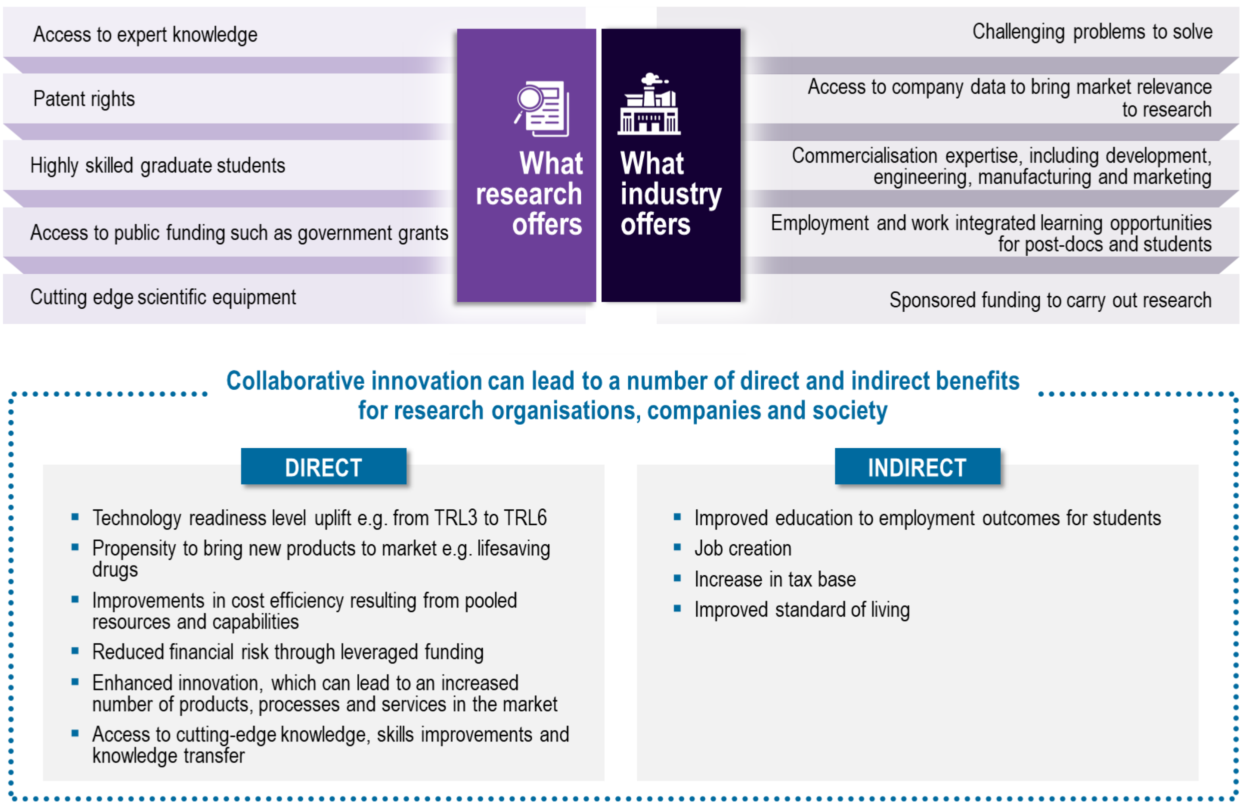
# 3 How AMAC generates impact

## 3.1 The role of research collaboration in economic growth

As mentioned in Chapter 2, AMAC was established through an ARC scheme that supports research collaborations between universities and industry. Collaboration between industry and researchers contributes to economic growth by delivering a range of benefits for businesses, research organisations and society in general. These benefits include (see Figure 3.1):

- enhanced innovation, which can lead to an increased number of products, processes and services in the market
- improvements in cost efficiencies resulting from pooled resources
- opportunities for businesses to obtain access to public funding, which can help to reduce financial risk
- access to cutting-edge knowledge, skills improvements and knowledge transfer.

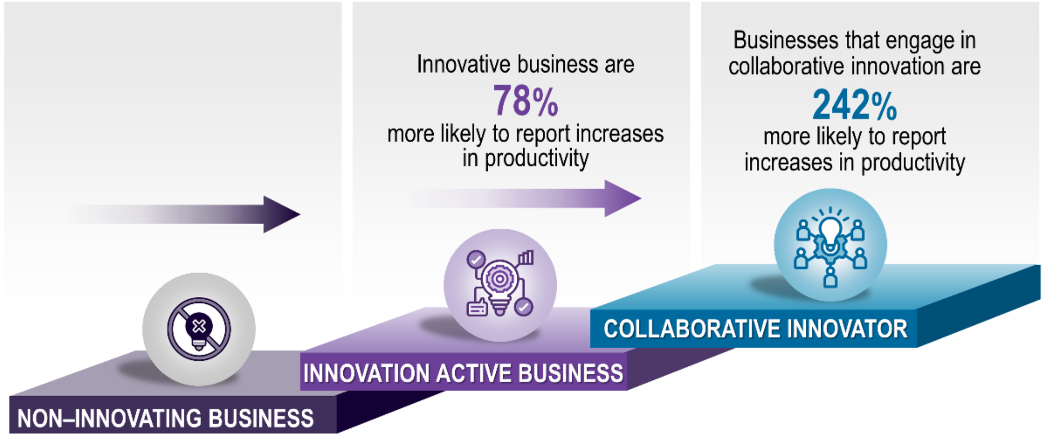
**Figure 3.1** Benefits of collaboration between industry and research organisations




*Source: Adapted from NSW Business Chamber 2014, Industry Research Collaboration Discussion Paper.*

Collaboration is a powerful tool for businesses to increase their level of innovation, become more productive and competitive and ultimately improve their bottom-line performance. Australian businesses that engage in collaborative innovation with research organisations are 242% more likely to report increases in productivity when compared with non-innovating businesses.[4] This is a threefold increase in the likelihood of productivity growth gained from collaboration (see Figure 3.2). Collaboration with research organisations is also strongly correlated with the degree of innovation novelty, with firms engaged in such collaboration being more likely to introduce world-first innovations.[5]

**Figure 3.2** Impact of collaboration on productivity




*Source: Adapted from NSW Business Chamber 2014, Industry Research Collaboration Discussion Paper.*

There is evidence that collaboration with universities leads to higher performance in companies. For instance, modelling by Cadence Economics shows more than $10.6 billion a year of all business income in Australia flows from collaborations with universities.[6] This averages to $662,000 for each of the 16,000 businesses that currently collaborate with a university. The estimated benefit to the national economy from these collaborations is $19.4 billion a year. This study also found a strong return on investment to companies of $4.50 for every $1 invested in collaborative university research in Australia. [7]

## 3.2 Impact pathway: a framework for understanding AMAC's contribution

High quality research is essential to enhancing productivity, driving international competitiveness, and increasing the living standards of Australians. Australia's capacity for science and innovation is strongly linked to its research collaborations. As discussed above, university-industry collaborations are vital for enabling leading-edge research and are central to the Australian innovation system.

To understand the impact of AMAC, it is important to understand how AMAC's facilities and personnel contribute to materials enhancement, process optimisation and risk reduction in the manufacturing process, and how this new knowledge is shared and applied to create impact in various contexts.

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[4] Department of Innovation, Industry, Science and Research (2013) cited in NSW Business Chamber (2014). Industry Research Collaboration Discussion Paper.

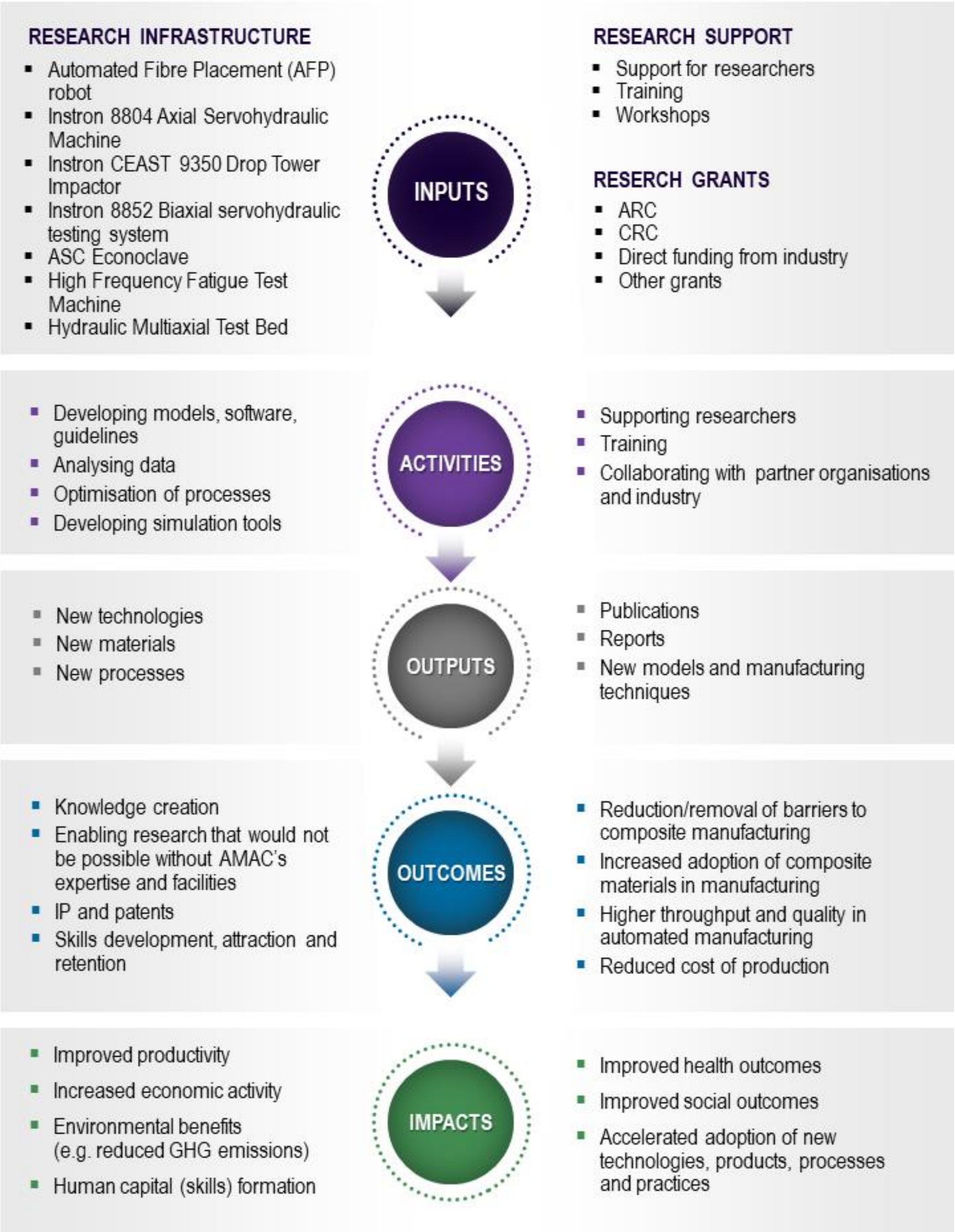
[5] Department of Industry. (2014). Australian Innovation System Report 2014.

[6] Universities Australia. (2018). Clever collaborations: the strong business case for partnering with universities. https://www.universitiesaustralia.edu.au/wp-content/uploads/2019/06/Clever-Collaborations-FINAL.pdf.

[7] Ibid.

To articulate how AMAC created value and frame an evaluation of its impact, we used an impact pathway. This impact pathway shows how AMAC's inputs and activities directly or indirectly influence research outputs and outcomes, which generate impacts on the broader community. This pathway for generating long-term impacts is depicted in Figure 3.3.

**Figure 3.3** AMAC's pathway to generating impact




*Source: ACIL Allen.*

As shown in Figure 3.3, broadly, AMAC generates impact by:

— enabling ground-breaking research addressing key challenges in composite materials and manufacturing processes

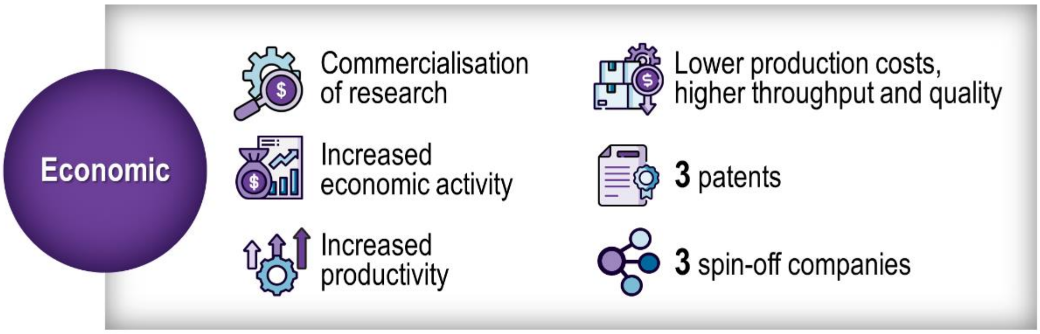
— facilitating the delivery of innovations that result in lower production costs, higher throughput and quality in automated manufacturing

— improving knowledge and skills in composite manufacturing through capability and capacity building of students and industry partners
— providing support to demonstrate proof of concept, develop a path to industry, and secure investment
— reducing the environmental impacts of operations.

These impact areas are discussed in more detail in the sections below. Quantification of impacts are presented in the following case study chapters.

### 3.2.1 Economic impacts

**Figure 3.4** Summary of economic impacts identified




*Source: ACIL Allen*

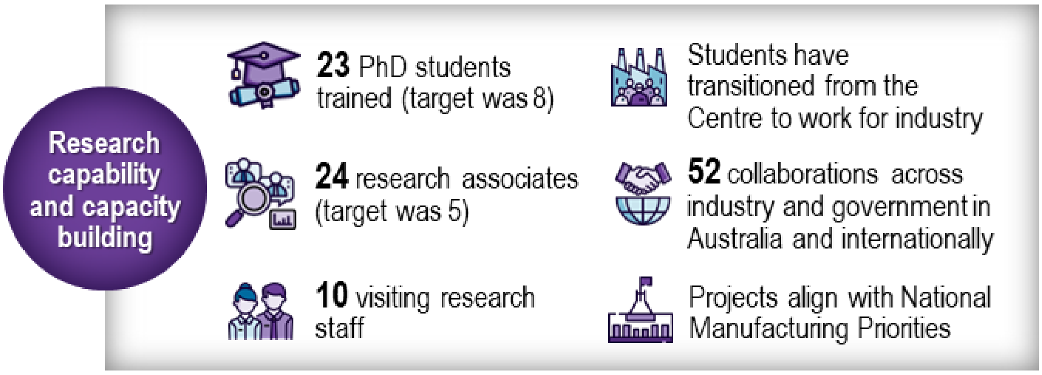
AMAC projects have created significant economic value, including through contributions to the **commercialisation of research** undertaken with its industry partners. Examples of successful commercialisations through AMAC's research collaborations include SDI Limited's successful launch of the *Stela* dental composite and planned release of *Luna Brux*, and the commercialisation of 3 out of 4 research collaborations with Omni Tanker, which involved developing composite tanker repair procedures, materials testing to support certification of tankers in the US market, and developing techniques for waterjet cutting of composite tanker components. The success of the waterjet cutting project resulted in Omni Tanker using funds received from the Manufacturing Modernisation Fund to procure and commission a new water jet machine. The successful commercialisation of research at SDI Limited and Omni Tanker has resulted in **increased economic activity**.

Much of AMAC's research also has the potential to realise economic and commercialisation benefits in the future. For example, composite propeller blade materials developed collaboratively between DSTG and AMAC may be used in defence applications or commercially, resulting in more fuel-efficient vessels in operation. The fibre optic structural health monitoring (SHM) systems developed collaboratively between AMAC and TfNSW are also expected to have future benefits for monitoring riveted steel bridges. TfNSW is planning future work that will leverage the AMAC research project, including on temperature sensors, continuous monitoring, and an SHM platform (a user-friendly program interface that interprets data for SHM). This future work may lead to **productivity benefits** in the monitoring of bridges in NSW (and other jurisdictions).

Through its research, AMAC addressed some of the key challenges in composite materials and manufacturing processes and delivered innovations that translated into **lower production costs, higher throughput and quality** in automated manufacturing. Furthermore, AMAC also enabled further economic benefits through 3 **spin-off companies**: Setonix Technologies, Nanostratus and New Frontier Technologies. Spin-off companies commercialise research outcomes, technologies, and ideas generated within universities. They translate research and ideas into marketable solutions, thus creating business opportunities and jobs. Three patents were also developed through AMAC research, including SDI Limited's *Luna Brux* line of products, which are expected to be commercialised in the future.

### 3.2.2 Research capability and capacity building

**Figure 3.5** Summary of research capability and capacity building impacts identified




*Source: ACIL Allen*

Over its 5 years in operation, AMAC delivered substantial contributions to Australia's research capability and capacity. As an ARC training centre, a key aim of AMAC was to build the capability of students and staff, and the capacity of industry partners to integrate innovations into their manufacturing processes and procedures.

AMAC set out to train a generation of composite manufacturing innovators at the frontier of industry-focused research and has achieved and exceeded expectations. To date, 23 **PhD students** have been trained, which exceeds the initial expectation of 8 PhD students trained under the ARC grant agreement. The addition of 24 **research associates** across various projects and 10 **visiting research staff** has exceeded the expected 5 research associates. This has provided AMAC with a strong platform to train researchers and allow them to provide significant value to industry projects and produce high-quality theses and journal articles.

Many former AMAC PhD **students** have **transitioned** from the Centre **to work for industry**, including for AMAC industry partners, where their expertise and ability to quickly integrate into advanced manufacturing businesses is highly valued. The impact of AMAC on capability uplift and workforce development is showcased in the case studies presented further in the report, which illustrate the potential economic impacts delivered/enabled by AMAC, as well as the research capability and capacity, social and environmental benefits that AMAC generated.

The research projects showcased in the case studies also highlight the value of **partnerships** between researchers, and **with governments, industry and not-for-profit organisations in Australia and internationally**. Partnerships enable sharing of information, data and expertise. They foster innovation and support the transfer of people and capacity between research and other sectors. AMAC facilitated a total of 52 collaborations/partnerships during their term.

The large number of academic personnel trained and engaged has allowed AMAC to draw on diverse ideas and perspectives to aid in the development of new and innovative processes and materials.

AMAC's research projects also build Australia's capacity in key National Manufacturing Priority areas. The National Manufacturing Priorities have been identified by the Australian Government as areas of national comparative advantage and strategic importance and underpin Australia's Modern

Manufacturing Strategy.[8] AMAC's alignment with these priorities include the research collaboration with SDI Limited, which aligns with the *Medical Products* national manufacturing priority area, and the research collaboration with DSTG, which aligns with the *Defence* national manufacturing priority area. This demonstrates AMAC's commitment to furthering important strategic areas of Australia's modern manufacturing sector, of which cutting-edge composite technology plays a critical role.

### 3.2.3 Environmental impacts

**Figure 3.6** Summary of environmental impacts identified


*Source: ACIL Allen*

Reducing the environmental impact of advanced manufacturing materials and processes is an important part of AMAC's collaborations, and AMAC projects have contributed to **minimising the environmental impact** of some of their industry partners.

A key example is the production of dental composites that have created a safer alternative to hazardous mercury-based amalgams, which can cause significant harms to human health and the environment when amalgam bi-products are released into the environment. (see Chapter 5 for further details). The CBA of the SDI collaboration estimates that the research will result in the avoidance of over 10 kg of mercury being released into the environment between 2023 and 2029 (this figure is adjusted for attribution to AMAC).

AMAC research has also resulted in repair procedures being implemented by Omni Tanker (a company that manufactures tank containers used to transport chemicals) in the European Union (EU), United States (US) and Australia for large industrial composite chemical tanks, resulting in an extension of the life of the tankers and **reducing landfill impact**.

Through a collaboration with the Australian Defence Science and Technology Group (DSTG), AMAC researched, tested and produced a shape adaptive marine propeller that in future may replace traditional metal components with robust, lightweight, rust-resistant composites with zero magnetic signature for stealth and defence operations. This may result in more efficient and longer-lasting propellers for marine applications. If commercialised, this technology would contribute to waste reduction and a diminished carbon footprint from reduced fuel consumption. AMAC has also applied composites in the transformation of bus chassis, which also resulted in similar **reductions in waste and fuel requirements.**

[8] DISR. (2020). Modern Manufacturing Initiative and National Manufacturing Priorities announced. https://www.industry.gov.au/news/modern-manufacturing-initiative-and-national-manufacturing-priorities-announced

### 3.2.4 Contribution to knowledge

**Figure 3.7** Summary of contribution to knowledge impacts identified


*Source: ACIL Allen*

AMAC has successfully contributed to **extending the technology and knowledge frontier in the advanced manufacturing sector**. Surpassing the initial goal of 50 journal publications, AMAC has achieved 109 publications in Q1 journals (the top 25% of ranked journals), one book chapter, 35 international conference papers, and delivered 14 invited/plenary/keynote talks. This is a significant accomplishment that has not only contributed to building the pool of knowledge but has also contributed to raising the academic profile and reputation of AMAC and all contributing partners. This level of productivity and engagement in academic and research activities reflects a strong commitment to scholarly contributions and knowledge dissemination and has resulted in awards for:

— Cooperative Research Australia (CRA) Enduring Industry-Research Collaboration Innovation Award, 2023.[9] This award is a prestigious recognition bestowed upon collaborative efforts between industry and academia that have resulted in groundbreaking advancements, technological innovations, and significant contributions to scientific knowledge. This award celebrates successful partnerships that bridge the gap between theoretical research and real-world applications, fostering a symbiotic relationship between the academic community and industry. By honouring these exceptional collaborations, the award not only promotes the spirit of innovation but also encourages further synergies between academia and industry to address complex challenges and drive societal progress.

— JEC Asia Innovation Award for 'Shape adaptive hydrofoil with fibre optic sensing' prototype design, 2019.[10] The research team manufactured the propeller blade using Automated Fibre Placement (AFP) technology. Prototypes were based on a digital design that were optimised throughout the process and manufactured at an unprecedented rate, while also minimising waste. The process also embedded fibre-optic sensors into the blade that provided strain measurements. These sensors were useful for prototyping and manufacturing, as well as performance and maintenance across the propeller blade's entire life cycle.

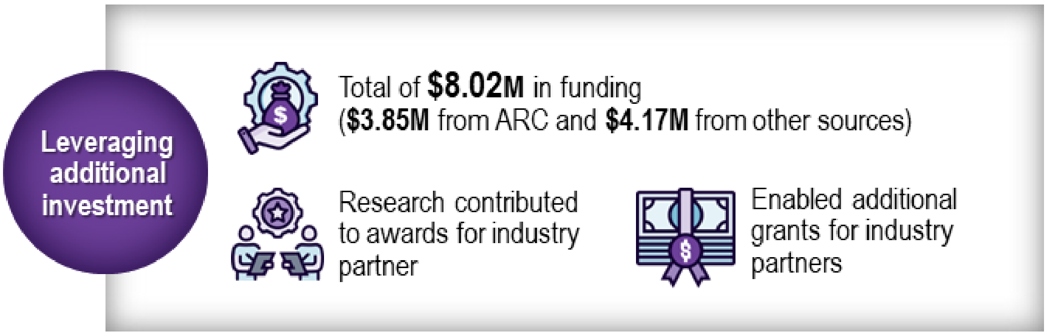
These awards, publications and research collaborations have further provided benefits to Australia by providing a foundation to enable further research to take place.

[9] CRA. (2023). Excellence in Innovation Awards. https://www.cooperativeresearch.org.au/events/excellence-in-innovation-awards/.

[10] JEC. (2019). JEC Asia Report. https://www.jeccomposites.com/news/spotted-by-jec/jec-asia-report/.

### 3.2.5 Leveraging additional investment

**Figure 3.8** Summary of leveraging additional investment impacts identified




*Source: ACIL Allen*

The performance of AMAC in attracting additional research funds beyond its initial ARC grant is a key indicator of the Centre's success as a leading research institution as this additional investment into Australia in turn generates economic benefits for other industries across the nation and expands Australia's competitive advantage in the global market.

Over the period 2017-2022, AMAC received $3.85 million in grant funding from the ARC. During the same period, AMAC successfully attracted $4.17 million in additional investment. This means that, for every dollar that AMAC received from the ARC during 2017-2022, the Centre attracted $1.08 in additional investment from other sources. This additional funding allowed AMAC to advance research, innovation, and the pursuit of knowledge.

Furthermore, AMAC's success has had positive impacts beyond the research that they are directly involved in. The portfolio of AMAC's research and its recognition and reputation in the composites sector has enabled further funding opportunities for its partners. For example, Omni Tanker has received 2 Innovation Connections grants and more recently funding through Lockheed Martin. Although this funding is not directly related to AMAC projects, Omni Tanker stakeholders consulted for this project noted that they reference work completed with AMAC in grant applications and when seeking funding, which contributes to their overall proposal.

AMAC has also contributed to industry partners receiving awards, such as SDI Limited winning the Australian Export Awards in the International Health category for outstanding international success in health and wellbeing in 2023.[11] SDI's Stela is mentioned specifically in relation to this award.

## 3.3 Upscaling AMAC's success: a composites manufacturing CRC

The success of AMAC contributed to the establishment of the Australian Composites Manufacturing Cooperative Research Centre (ACM CRC, previously known as the Sovereign Manufacturing Automation for Composites Cooperative Research Centre), which was announced on 11 May 2022. The successful $70 million bid for ACM CRC was led by Professor Gangadhara Prusty, Director at AMAC.

ACM CRC upscales the success of AMAC and leverages its industry and academic connections. ACM CRC was established in partnership with 6 Australian Universities, the Australian Nuclear

[11] Australian Export Awards. (2023). International Health winner. https://www.exportawards.gov.au/en/stories/2023-awards/international-health-winner

Science and Technology Organisation (ANSTO) as well as more than 25 key industry partners. The industry partners will invest a further $190 million into the CRC.[12]

The ACM CRC seeks to build a digital-export-ready composites industry with cost-competitive, high-quality platform capability through intelligent automation, technology innovation and new product demonstration. Similarly to AMAC, the ACM CRC has 4 research programs[13]:

1. Composite Materials – addressing key challenges in materials so they meet automation, affordability and circular economy requirements.
2. Manufacturing Processes – focusing on intelligent manufacturing and the digital value chain, sensor integration and hybrid structures incorporating dissimilar materials and additive manufacturing advances.
3. Simulation, Performance Prediction – developing simulation and performance prediction technologies for composite materials, supporting critical technology and know-how implementation and building analyses for the circular economy.
4. Desing, Integration – enhancing design processes for digital manufacturing and increased requirements for certification-ready designs with demonstration and field installation of composite structures for technology validation.

Through these programs, the ACM CRC aims to de-risk investment in composites manufacturing, while simultaneously strengthening and growing the transport, hydrogen, space, defence, circular economy and consumer sectors. Impact modelling for the CRC over the next 15 years indicates it will contribute:

— $8.3 billion of direct economic benefit to the economy by capitalising on emerging sectors that need advanced composite materials
— 1,500 direct jobs.

[12] UNSW. (2022). New CRC Grant awarded to UNSW research group will pave the way in Composite Manufacturing. https://www.unsw.edu.au/news/2022/05/new-crc-grant-awarded-to-unsw-research-group-will-pave-the-way-in-composite-manufacturing

[13] ACM CRC. (2024). AMC CRC Webpage. https://www.acmcrc.com/research-program-1-composite-materials

# Exploring AMAC's impact: analysis framework

# 4

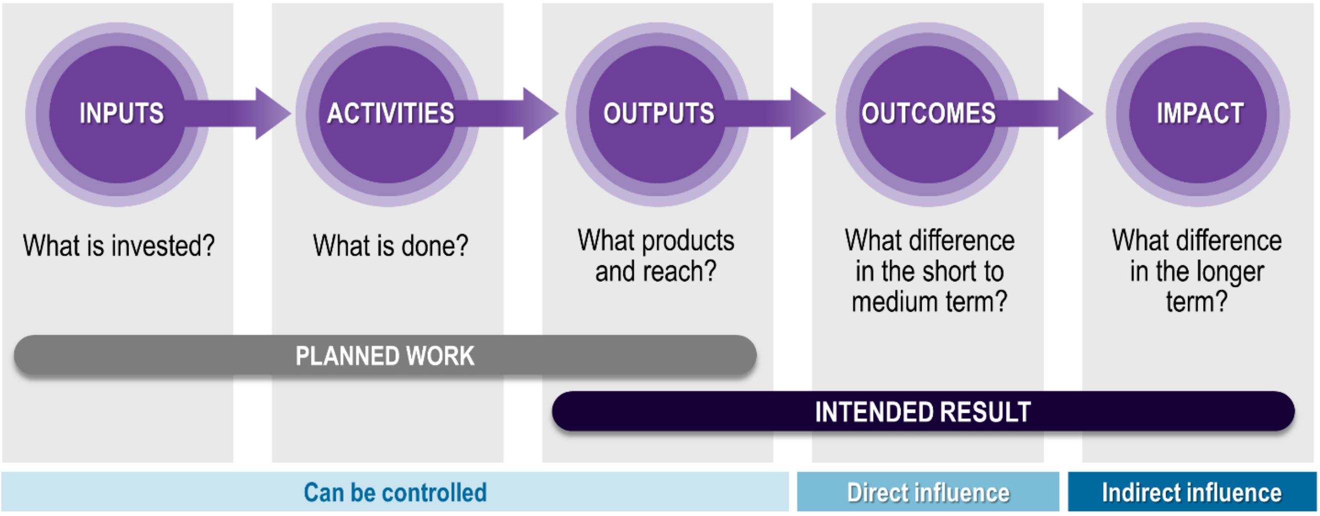
## 4.1 Overarching assessment framework

ACIL Allen has adopted a case study approach to highlight the impact and value of AMAC. This approach has been used for a large number of similar assessments of other research organisations. For this report, we examined 4 case studies selected by AMAC as representative of the nature of the work they undertook during its operations.

These case studies provide plausible and defensible lower bound estimates of the returns of AMAC's collaborative research, particularly in terms of the return on investment to governments. Furthermore, while case studies do not provide statistical representativeness, through purposeful sampling they illustrate aspects of the research's impact mechanism.

The case studies have been undertaken using an impact pathway. This framework is underpinned by a model that seeks to determine the relationship between the research inputs (resources), research activities, research outputs, research outcomes, and the potential economic, social and environmental impacts generated from the research (see Figure 4.1). ACIL Allen has used this framework to evaluate the impact and value of research done by a large number of scientific organisations.[14]

**Figure 4.1** Impact pathway




*Source: ACIL Allen.*

[14] The approach is based on that outlined in the CSIRO Impact Evaluation Guide. The most recent version of the guide can be seen at: https://www.csiro.au/en/about/Corporate-governance/Ensuring-our-impact/Evaluating-our-impact.

An impact pathway consists of:

- **Inputs** – the resources used/invested in the project to implement it and deliver the intended results, including financial resources (project funding), human resources (personnel) and organisational resources
- **Activities** – the actions taken, or work performed that is associated with delivering the project goals (what the project does with the inputs)
- **Outputs** – the products, services, capacities and/or solutions that result from the completion of activities within a project (i.e. the direct results of project activities)
- **Outcomes** – what the project has achieved (or is intended to achieve) in the short to medium term from the delivery of the program outputs
- **Impacts** – the long-term consequences (positive or negative) of a project on the economy, environment or society.

In general terms, a project's inputs, activities and outputs can be controlled, while outcomes and impacts can only be influenced (directly or indirectly) through the project's activities and outputs.

## 4.2 Approach to measuring impacts

We have used a cost-benefit analysis (CBA) approach to assess the value delivered by the case studies. This approach compares the costs and benefits of the selected AMAC case studies. The direct costs for the research conducted by AMAC are mainly borne by the Commonwealth Government through research grants. The direct monetary benefits accrue to AMAC's industry/government partners and the Australian community overall (e.g. through increased tax revenues, reduced environmental damage, etc.).

As with any attempt to project potential future benefits, it is necessary to make a number of assumptions. We have been transparent about those assumptions and have sought to ensure that they are well informed, while at the same time adopting a conservative approach to any assumption we make.

The information gathered through data collection for the purposes of demonstrating AMAC's impact pathway has informed the quantitative CBA of each research project. The CBA for each case study includes 2 summary measures to distil the results of the analysis, as described in Table 4.1.

**Table 4.1** Summary of measures included in the CBA

| Summary measure | Description | Success measurement | Comparative ability |
|---|---|---|---|
| Net present value (NPV) | Sum of discounted annual net benefits (benefits minus costs) | Research is beneficial to society if NPV is greater than zero | Provides the ability to compare the projects analysed according to the total economic return of each. |
| Benefit-cost ratio (BCR) | Ratio of the present value of total benefits to the present value of total costs | Research is beneficial to society if BCR is greater than one | Provides the ability to compare the projects analysed to the degree to which benefits outweigh costs for each. |

*Source: ACIL Allen.*

Significant non-quantifiable impacts have also been identified, which are important to consider alongside the CBA results and have therefore been included in each of the case studies. The significant impacts of AMAC's training are described qualitatively in a separate chapter which documents the results of the AMAC PhD and researcher survey. The non-quantifiable impacts identified include:

— the contribution of AMAC to knowledge through publications and knowledge sharing
— capability and capacity building through training
— enabling impacts, for example of grants and the ACM CRC.

These impacts are included thorough the report and form part of the broader narrative of the benefits generated by AMAC.

### 4.2.1 Data collection

Three methods of data collection were used to collect evidence for the impact analysis. These methods are outlined below.

**Document review**

ACIL Allen conducted a document review of relevant documents supplied by AMAC on the research projects, as well as publicly available literature reviews, market analysis and reports. Through this process, ACIL Allen developed assumptions for the impact framework and CBA to further test with stakeholders during the interview process.

**Stakeholder interviews**

ACIL Allen interviewed an industry stakeholder for each of the 4 research projects undertaken. The interviews were used to provide additional information about the impact framework (inputs, activities, outputs, outcomes and impacts) and test assumptions and the approach to the CBAs. This involved preparing a discussion guide and holding one-hour discussions on the AMAC's role in the projects, and the costs, benefits, and current and expected commercialisation levels of the research. Questions on other impacts such as those on training, knowledge transfers, spin-off companies and publications development, and any grants and awards received were also included.

**PhD and researcher survey**

A short PhD and researcher survey was distributed to relevant stakeholders identified by AMAC. The survey received 30 responses in total. The survey asked 5 Likert-scale questions in relation to the quality of training through AMAC, the relevance of the training to industry application, the importance of AMAC to the realisation of achievements, whether the same training could be received elsewhere and how likely the responders would be to recommend AMAC to others. An open-text question on the research conducted at AMAC was also included. The results of this survey have been presented in Chapter 9.

# Case study: Dental Composites 5

The 2013 Minamata Convention on Mercury is an internationally legally binding treaty that aims to protect human health and the environment from anthropogenic emissions and release of mercury and mercury compounds. The convention proposed 9 measures to phase down the use of dental amalgam by 2020. One of these measures suggests that dental schools should educate and train dental professionals and students on the use of mercury-free dental restoration alternatives. These measures show the interconnected nature of phasing down dental amalgams and reinforce the need for a multipronged approach, as called for by the World Health Organization (WHO).[15]

**The Stela system**


*Source: SDI*

SDI Limited (SDI) is a leading manufacturer of specialist dental materials marketed in over 100 countries globally. Through collaboration with AMAC, SDI developed *Stela*, a breakthrough technology that replaces amalgams. Stela is an innovative high-performance self-cure composite that delivers stronger and more efficient dental restorations.

The Stela technology is the result of a strong partnership between SDI's scientists and 3 leading Australian universities: the UNSW, the University of Sydney and the University of Wollongong. Stela was developed over a 5-year timeframe via a rigorous and scientifically proven process and supported by the government via grants.

This case study describes the economic, environmental and social benefits arising from the AMAC-SDI collaboration, which resulted in the creation of the Stela technology.

This evaluation is being undertaken to assess the positive impacts arising from projects undertaken by AMAC. This case study can be read as a standalone report or aggregated with other case studies to substantiate the impact and value of AMAC’s work in supporting the next generation of automated composite manufacturing innovations and innovators, and to estimate the return on the investment from the funds spent on these activities.

## 5.1 Impact Pathway

A high-level impact pathway for AMAC’s project on dental composites is summarised in Figure 5.1.

[15] Reher V, Reher P, Peres KG, Peres MA. (2021). Fall of amalgam restoration: a 10-year analysis of an Australian university dental clinic. Aust Dent J. Mar;66(1):61-66.

**Figure 5.1** Dental composites impact pathway

| INPUTS | ACTIVITIES | OUTPUTS | OUTCOMES | IMPACTS |
|---|---|---|---|---|
| – Cash support from ARC linkage and CRC grants<br>– AMAC research expertise in fibre-reinforced dental material technology<br>– SDI commercial manufacturing capability and experience | – CRC-P grant preparation support<br>– Research and development of novel-fibre reinforced dental composite system<br>– Clinical evaluation of newly developed materials | – Creation of Stela, a mercury-free, self-curing resin based flowable dental filling material<br>– Generation of project IP and Patent for Luna Brux line of products<br>– Journal articles and conference presentations<br>– Increased skills and knowledge (PhD students and researchers trained) | – Faster, stronger and more efficient dental restorations through Stela<br>– Reduced risk of premature failures and increased longevity of Stela restorations compared to other dental composites due to elimination of polymerisation shrinkage<br>– Uptake of self-cure dental composites in 100 countries by 2024-25<br>– Potential future outcomes for consumers, SDI Limited and UNSW from Luna Brux<br>– SDI received the Australian Export Awards in the International Health category in 2023 | **Economic**<br>– Increased economic activity and employment<br>– Increased export revenues[16]<br>– Advancements in SDI's commercial manufacturing capability<br>– Opportunities for potential strategic engagement with external parties<br>**Environmental**<br>– Reduced environmental impact from mercury leakage.<br>**Social**<br>– Improved patient outcomes |

*Source: ACIL Allen, AMAC*

### 5.1.1 Project inputs

As discussed before, project inputs refer to the resources used/invested in a project to implement it and deliver the intended results. In this case study, this refers to resources invested by AMAC in the dental composites project.

AMAC received 2 research grants for this project (see Table 5.1). The resources (in cash and in kind) invested by SDI are not included in this analysis due to confidentiality issues.

**Table 5.1** Cash support for the dental composites project

| Grant Body | Grant Amount | Duration |
|---|---|---|
| ARC | $375,162 | 3 years (2016-2019) |
| CRC-P | $1,681,188 | 3 years (2019-2021) |
| **Total** | **$2,056,350** | |

*Source: AMAC*

[16] All of SDI's products are manufactured in Victoria.

### 5.1.2 Project activities

AMAC contributed to 2 significant activities through this research collaboration. The first activity was the preparation of the CRC-P grant awarded to the project. SDI Limited stated that staff at AMAC were experienced in building a strong narrative around research grant applications, particularly in relation to university resources, recruitment and training of PhD students, previous projects and the development of publications, and this expertise contributed to receiving the grant.

The second activity was the materials research, modelling and testing, which was undertaken in order to develop the dental composite materials. SDI Limited stated that partnering with AMAC to undertake this research was beneficial given the combined expertise held by the parties. SDI Limited have been manufacturing dental products for over 50 years, and AMAC brought significant experience in composites manufacturing which provided insight and evidence to support the technology. This meant that the research was both scientifically robust but also had a strong focus on commercialisation. Specific research activities undertaken through the collaboration included:

— Examining mechanical and physical characteristics such as strength, modulus, toughness, polymerisation shrinkage and stress, and rheological properties of dental materials (ceramics, composites, and human teeth).
— Investigating coupled temperature-displacement in reinforced dental composites.
— Analysing dental composite stress at the restoration-tooth Interface due to mechanical loadings.
— Evaluating fracture toughness of dental resin composites.
— Developing the density–modulus relationship for enamel and dentine.
— Investigating biomechanical behaviour of functionally graded biomaterial dental implants.

### 5.1.3 Project outputs

The outputs of the dental composite project include:

— new dental filling materials and products
— new project IP
— journal articles and conference presentations
— increased skills and knowledge.

These are discussed in more detail in the sections below.

**New materials and products**

The research collaboration resulted in the development of SDI's patented dental composite system *Stela*. Stela, which SDI markets as 'the true amalgam alternative', is a mercury-free, self-curing resin based flowable dental filling.

**New project IP**

The work of AMAC and SDI has also resulted in the creation of new IP for Luna Brux, another dental composite developed through the collaboration with differing properties to Stela; Luna Brux is reinforced with surface-treated short glass fibres. SDI Limited expect to commercialise this product imminently.

**Journal articles, conferences and awards**

Table 5.2 summarises the AMAC's publications, conferences and awards over the period 2017-2022.

**Table 5.2** AMAC's publications, conferences and awards

| Category | Benefit |
|---|---|
| ME/BE Thesis Produced | 10 |
| Journal Articles published | 21 |
| Conference presentations | 5 |

*Source: AMAC*

Academic journal articles provide a more current view of research areas than textbooks and possess a high level of credibility due to the process of peer review. Through the AMAC and SDI collaboration 21 journal articles were published providing multiple intangible benefits to society and to AMAC.

Firstly, through the publication of journal articles, the AMAC and SDI collaboration has advanced the knowledge frontier in the advanced materials manufacturing sector. This has contributed to extending other researchers' access to existing knowledge and may have a multiplier effect on advancements in dental composite technology.

Further, by publishing in academic journals, presenting at conferences and receiving awards, AMAC has raised the profile of their research and undertaken networking activities. This provides increased opportunities for future collaborations with other academics and industry partners which may lead to the production of further patents in the future, which could lead to royalty income derived from licensing agreements. Increased levels of funding may also be received due to improving academic reputation and history of success engaging in industry collaborations.

Research funding in the form of grants such as ARC and CRCP grants are important sources of funding for universities, with UNSW receiving $526.7m of funding from grants in 2022[17]. The success of the AMAC staff is likely to improve their academic reputation and experience in writing grant applications leading to an increased likelihood of receiving grant funding in the future.

Two student awards were part of this journey:

— Kiho Cho – International Association for Dental Research (IADR) – STAR Network Academy fellowship, 2020

— Arcade Serubibi – The Best Student Paper Award, 10th Australasian Congress on Applied Mechanics (ACAM10), Adelaide, 2021.

Finally, the increase in publications and academic reputation is likely to contribute to the overall university rankings which may lead to higher levels of student enrolments, grant funding received and academic collaboration with external entities.

### Increased skills and knowledge

SDI Limited noted that the COVID-19 pandemic stifled opportunities for AMAC and SDI Limited students and researchers to travel between the 2 organisations to work on projects in person. Despite this, the project resulted in the successful training of 4 PhD students, which is a significant achievement. This demonstrates the Centre's dedication to the training of its students.

[17] Department of Education. (2024). Higher Education Research and Development Income time series (1992-2022). https://www.education.gov.au/research-block-grants/resources/research-income-time-series

### 5.1.4 Project outcomes

#### Commercialisation of Stela

The key outcome of the project was the successful development and commercialisation of Stela, which offers significant benefits over other dental filling alternatives.

— Stela is a dental composite made from material that is more durable relative to other composites currently available on the market.
— Stela's composite materials can be placed in a patient without using etch, prime, bond and light cure process required by competitor products, reducing placement time to 15 seconds instead of 120.
— An additional benefit of the removal of the light curing process is that polymerisation shrinkage does not occur (wherein polymerisation of the composite begins closest to the light source, creating shrinkage of the composite and pulling material away from the cavity walls). Shrinkage can introduce gaps between the composite and the tooth, increasing the risk of re-introducing decay.
— Dental composite fillings provide aesthetic benefits to consumers as they blend into the surrounding teeth and do not have a metallic finish like amalgams. Stela provides additional benefit to consumers relative to other composite materials by being produced without amine, which can lead to the yellowing of restorations over time.

These beneficial characteristics of Stela have contributed to the realisation of economic, environmental and social impacts. In 2023, SDI Limited stated that it expects to export Stela to almost all 100 of its current export markets by 2024-25.[18]

#### Potential future outcomes from Luna Brux

Although not commercialised yet, Luna Brux is likely to result in future outcomes for consumers, SDI Limited, and UNSW. Luna Brux has different properties from Stela and therefore is likely to have different use cases. It is a light cured material, which contains short glass fibres making it strong and fracture resistant in high stress areas. Potential use cases cited by SDI Limited include restorations for patients who excessively grind their teeth. Luna Brux may lead to future benefit streams for SDI Limited, from sales revenue of the product, but also to UNSW which holds the patent for the Luna Brux, and therefore will receive royalty payments for any potential sales of the Luna Brux product in the future.

#### Awards

In 2023, SDI limited won the Australian Export Awards in the International Health category for outstanding international success in health and wellbeing.[19] SDI's *Stela* is mentioned specifically in relation to this award.

### 5.1.5 Project impacts

#### Economic

Through the AMAC collaboration, SDI's commercial manufacturing capability has been improved allowing SDI to produce higher value advanced dental composites, in line with consumer

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[18] Australian Export Awards. (2023). International Health winner. https://www.exportawards.gov.au/en/stories/2023-awards/international-health-winner

[19] Ibid.

preferences. The creation of new product lines will also aid SDI transition away from revenue streams exposed to the phase-out of mercury use under the Minamata convention.

SDI further reported that the time taken to produce and transport their amalgam line of products is somewhat delayed due to approval processes involved with the movement of mercury products. By developing a dental composite material with AMAC and replacing their amalgam product line in Australia by 2030 it is likely that processing times for SDI products will reduce. This will result in a time saving for SDI which may be allocated to more productive activities. In producing higher value dental composites, it is likely that SDI will also realise increased export revenue and contribute to economic growth through the employment of high skilled labour required to produce advanced dental composites, section 5.2.2 attempts to quantify some of these benefits. Positive reviews and awards won for the production of the Stela product line have also improved SDI and AMAC's reputation and may provide a platform for increased engagement with external parties on similar projects in the future.

**Environmental**

Currently dental amalgams are produced using mercury (and a range of other metals). Throughout the installation process and decay throughout their life, amalgam fillings leak mercury into patients and into the environment. Usage of the Stela product line by dentists will provide an environmental benefit by minimising the leakage of mercury into the natural environment.

**Social**

Dental amalgams provide a durable, long-lasting material, however, have a metallic finish that some consumers do not prefer. In contrast fillings made from composite materials provide a more natural look that easily blends into the shape and colour of surrounding teeth. Some consumers have an aesthetic preference for dental composites and are likely to derive more value from these products relative to amalgams.

Quantified project impacts are described further in Section 5.1.6 below.

### 5.1.6 Clarifying the impacts

When estimating the impacts of AMAC's research, ACIL Allen must ensure that the benefits and costs counted in the analysis are compared against the 'baseline scenario'. This scenario estimates the trajectory of outcomes in a world where AMAC did not undertake the research project. Importantly in the case of this project, there is an existing trend in the phasedown of amalgams, and a complete phase out of amalgam use by Australian dentists is expected by 2030 due to the implementation of the Minamata convention. This is considered when calculating the avoided health costs described, as benefits in the CBA must be additional to what is already likely to occur under the baseline scenario.

**Attribution**

Attribution represents the extent to which AMAC enabled impacts that have occurred because of this collaborative project. Benefits from the research project must be adjusted for attribution to AMAC to acknowledge the important work of other parties involved in the research collaboration. AMAC's attribution has been estimated at 25% noting that the research collaboration also involved the industry partner (SDI Limited) and 2 other university partners (University of Sydney and the University of Wollongong). This figure has been applied to the avoided health benefits and the value added to the Australian economy.

## 5.2 Estimated impacts

As discussed in Section 4.2, we have used a CBA framework to assess the value delivered by the AMAC-SDI collaboration. The following sections outline the costs and benefits captured in this analysis.

### 5.2.1 Costs

As outlined in Table 5.1, the nominal research costs of the AMAC-SDI collaboration totalled $2.1 million (equivalent to $2.4 million in 2023 prices) incurred between 2017-2022.

The present value (PV) in 2023 of these costs using a 7% real discount rate is $3.0 million (in 2023 dollars). It has been assumed that research funds were distributed equally during every year of the grant.

### 5.2.2 Benefits

We have estimated 2 benefits related to the SDI-AMAC collaboration:

— Higher levels of economic activity due to additional revenue from high-performance composites for dental restorations. We have captured this benefit through estimates of value added.[20]

— Avoided health impacts associated with mercury leaks from amalgams.

These benefits are discussed in more detail below.

**Value added to the Australian economy**

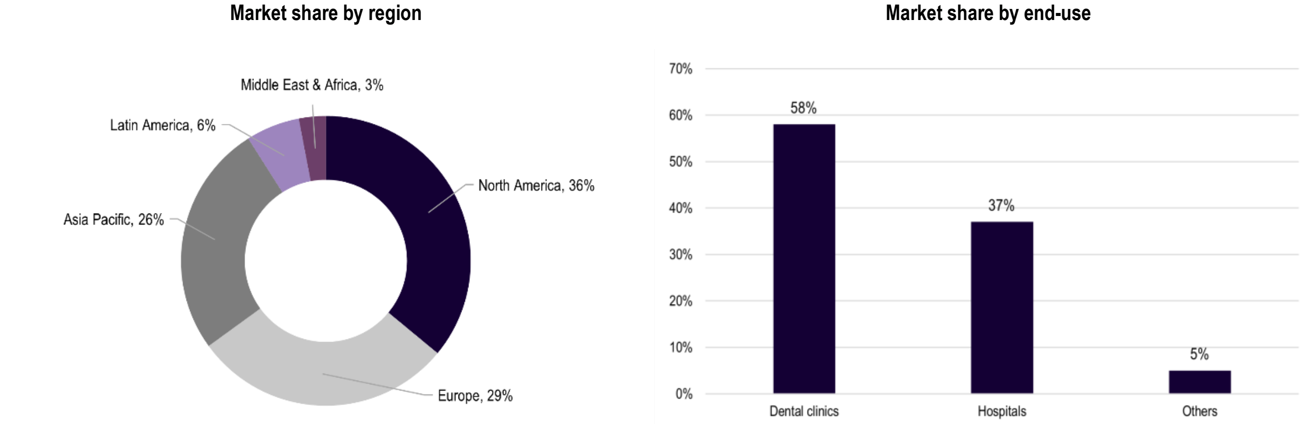
As noted before, AMAC's work with SDI enabled the production of Stela, a high-performance composite for dental restorations. The development of advanced dental composite materials is likely to contribute to higher levels of economic activity through increased revenue to SDI, purchasing of higher value input materials and employment opportunities.

A report by Precedence Research[21] estimates that the global market for tooth filling materials in 2023 was valued at USD$2.17 billion and that this market will reach USD$3.72 billion in 2033, growing at a compound annual growth rate (CAGR) of 5.53% between 2024 and 2033. The report also provides separate estimates of the size of the tooth filling materials market by region and by end-use (see Figure 5.2) and notes that by product, the composite resin segment had over 36% of market share in 2023.

[20] Value added measures the contribution of high-performance dental composites sold by SDI to the Australian economy by measuring their impact on wages, salaries, profits and indirect taxes.

[21] Precedence Research. (2024). Tooth Filling Materials Market, April.

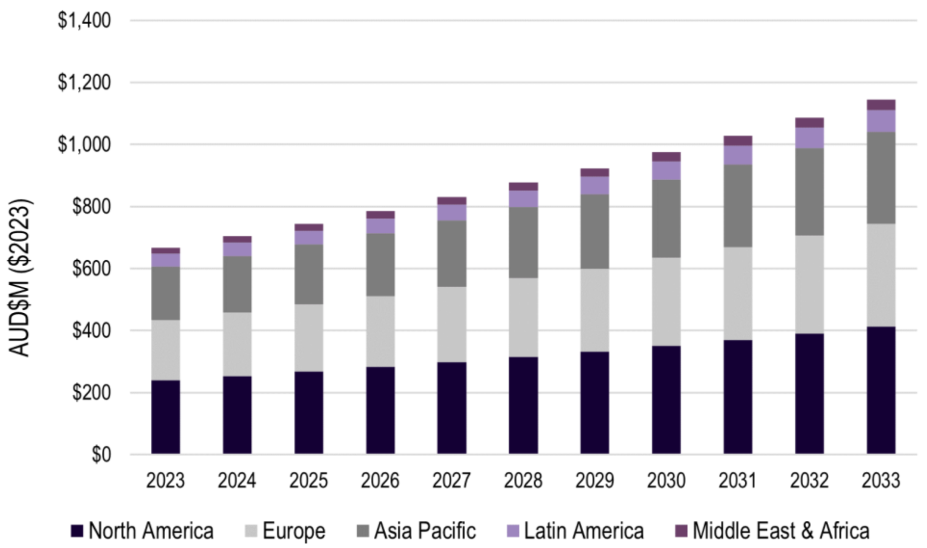
**Figure 5.2** Global tooth filling materials market by region and end-use, 2023




*Source: Precedence Research 2024, Tooth Filling Materials Market, April.*

Using the information in this report, we estimate that the global market for composite tooth filling materials by dental practices in 2023 was around AUD$668 million, growing to around AUD$1.14 billion in 2033 (see Figure 5.3).

**Figure 5.3** Market for composite tooth filling materials by dental practices, 2023 to 2033 ($m, 2023 dollars)




*Source: ACIL Allen based on Precedence Research 2024, Tooth Filling Materials Market, April.*

SDI exports its products to over 100 countries, with the majority of its revenue generated from Australia (see Figure 5.4). Assuming that the market for tooth filling materials in each of the countries where SDI generates revenue from is in line with the size of their economies, then, given the size of:

— the Australian economy (around USD$1.7 trillion in 2022 according to World Bank estimates), the market for composite tooth filling materials by dental practices in Australia could be around USD$6 million (AUD$9 million) in 2023

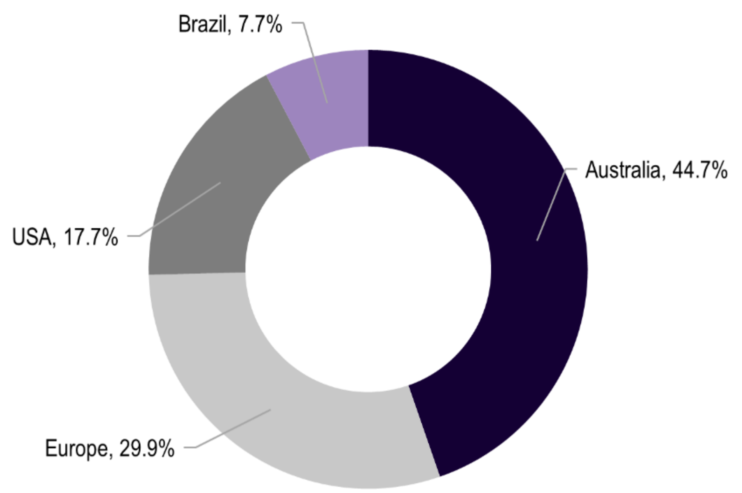
— the Brazilian economy (around USD$1.9 trillion in 2022 according to World Bank estimates), the market for composite tooth filling materials by dental practices in Brazil could be around USD$9 million (AUD$13 million) in 2023

— the US economy (around USD$25.4 trillion in 2022 according to World Bank estimates), the market for composite tooth filling materials by dental practices in the US could be around USD$150 million (AUD$221 million) in 2023.

The European market (where around 30% of SDI's revenue is generated from) for composite tooth filling materials by dental practices could be around USD$131 million (AUD$194 million) in 2023.

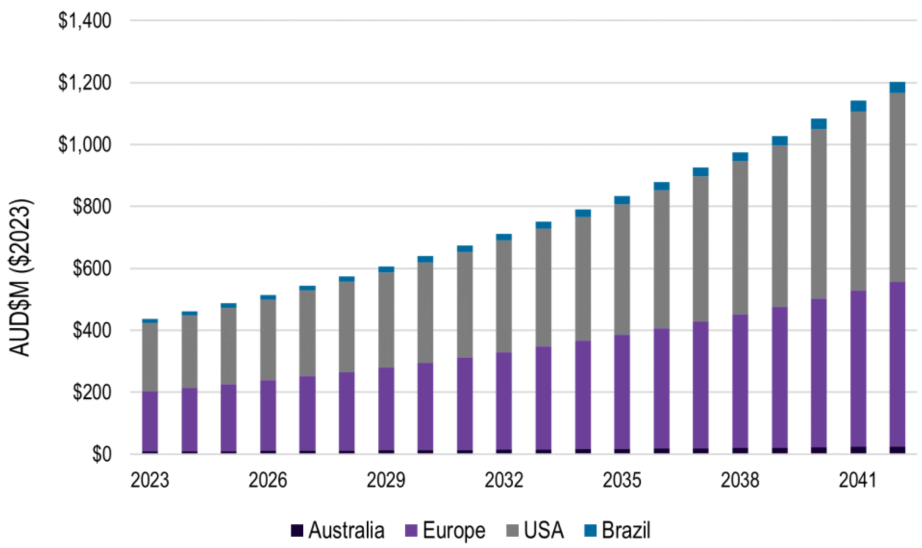
The size of the markets for tooth filling materials in dental practices relevant to SDI is projected between 2034 and 2042 assuming a CAGR of 5.53% (see Figure 5.5).

**Figure 5.4** SDI revenue by location




*Source: ACIL Allen based on IBISWorld, SDI Limited Company Profile, 30 June 2023.*

**Figure 5.5** Market for composite tooth filling materials by dental practices in markets from which SDI generates revenue, 2023 to 2042 ($m, 2023 dollars)

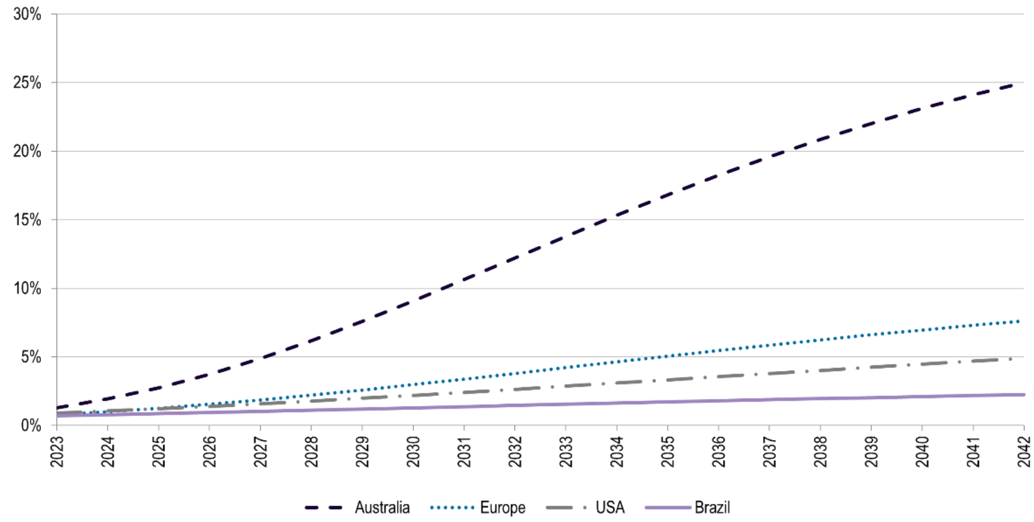



*Source: ACIL Allen based on Precedence Research 2024, Tooth Filling Materials Market, April.*

The potential benefits to Australia from adoption of SDI dental composites enabled through AMAC research (in terms of value added) were assessed based on:

— the market estimates in Figure 5.6
— assumptions about the adoption of SDI's high performance dental composite in these markets (shown in Figure 5.6). We have assumed that SDI dental composites achieve a market share by the end of the projection period (2042, 20 years from the year that the technology went to market) of:
  - 25% in Australia
  - 7.5% in Europe
  - 5% in the US
  - 2.5% in Brazil
— the following assumptions:
  - that value added by the dental composites industry represents around 36% of its revenue
  - that, as discussed in Section 5.1.6, 25% of the benefits generated by SDI were enabled/can be attributed to AMAC's research.

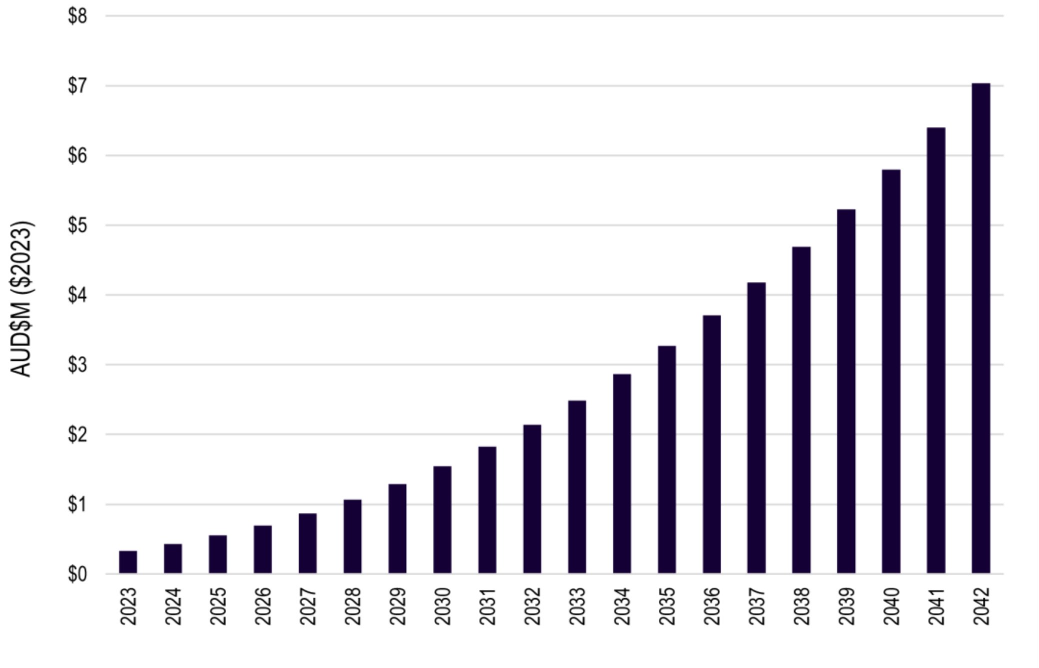
**Figure 5.6** Assumed adoption of SDI dental composites across different markets




*Source: ACIL Allen.*

The potential benefits to Australia from adoption of SDI's dental composites derived from research undertaken by AMAC over the period 2023 to 2042 shown in Figure 5.7. The present value in 2023 of these benefits using a 7% real discount rate is $24 million (in 2023 dollars).

**Figure 5.7** Potential benefit to Australia from sales of dental composite filling materials derived from AMAC's research, 2023 to 2042 ($m, 2023 dollars)




*Source: ACIL Allen.*

**Avoided health costs**

Mercury products are a source of negative health impacts on society in Australia. The uptake of composites produced by the SDI-AMAC collaboration is expected to result in reduced negative health impacts of mercury. This section describes how ACIL Allen estimates the avoided health costs attributable to SDI Limited and AMAC.

A report[22] prepared for the Department of Environment and Energy presented several assumptions on the costs and benefits of Australia phasing down mercury. These impacts included negative impacts on health, which showed that:

— Mercury is estimated to reduce the Australian population's IQ at a cost to society of $6,088 per kilogram of mercury entering the environment.

— Mercury emissions are estimated to impact heart attacks in Australia at a rate of $27,396.20 per kilogram of mercury entering the environment.

The report also estimates that 0.45kg of mercury enters waterways per dental practice from the use of amalgam annually.

This information on the negative health impacts and the amount of mercury released into the environment needed to be applied to estimates over time of the number of dental practices using amalgams. As of 2018 there are an estimated 7,400 dental clinics in Australia.[23] ACIL Allen has used this information and ABS population projections to estimate the growth in dental clinics to 2042. A 2023 study on amalgam versus composite use in the US was analysed and it was found

[22] Department of Environment and Energy. (2018). Costs and benefits of Australia phasing down mercury. https://www.dcceew.gov.au/environment/protection/publications/cost-benefits-australia-phasing-down-mercury

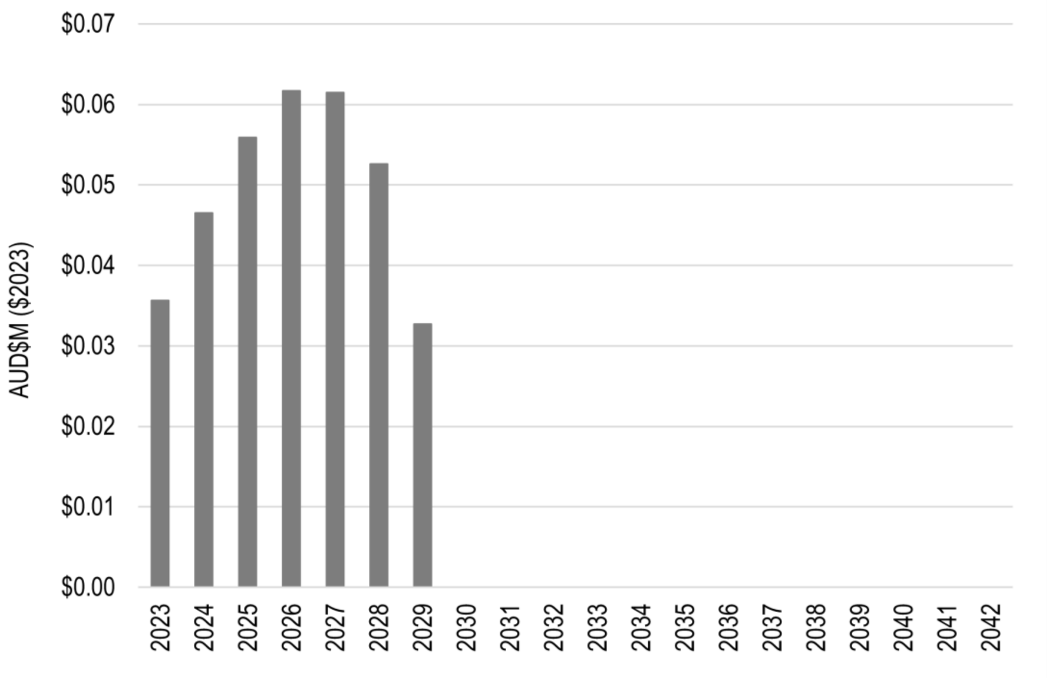
[23] Ibid

that dental practices using amalgams had fallen from 31.3% in 2010 to 13.7% in 2020[24]. ACIL Allen has used this data to assume that the proportion of dental practices that use amalgams will follow a similar trend in Australia, until a complete phase out of Australian dentists using amalgams by 2030 due to the implementation of the Minamata convention.

These assumptions developed through the literature review allowed ACIL Allen to estimate the amount and health cost of mercury entering the environment from dental practices in Australia from 2023 to 2042. These figures were then adjusted for the assumed adoption of SDI dental composites (see Figure 5.6). As discussed in Section 5.1.6, 25% of the benefits generated by SDI were enabled/can be attributed to AMAC's research.

The potential avoided health costs from the adoption of SDI's dental composites derived from research undertaken by AMAC over the period 2023 to 2042 is shown in Figure 5.8. The present value in 2023 of these benefits using a 7% real discount rate is $0.3 million (in 2023 dollars).

**Figure 5.8** Potential health benefits to Australia from reductions in mercury leaks from amalgams, 2023 to 2042 ($m, 2023 dollars)



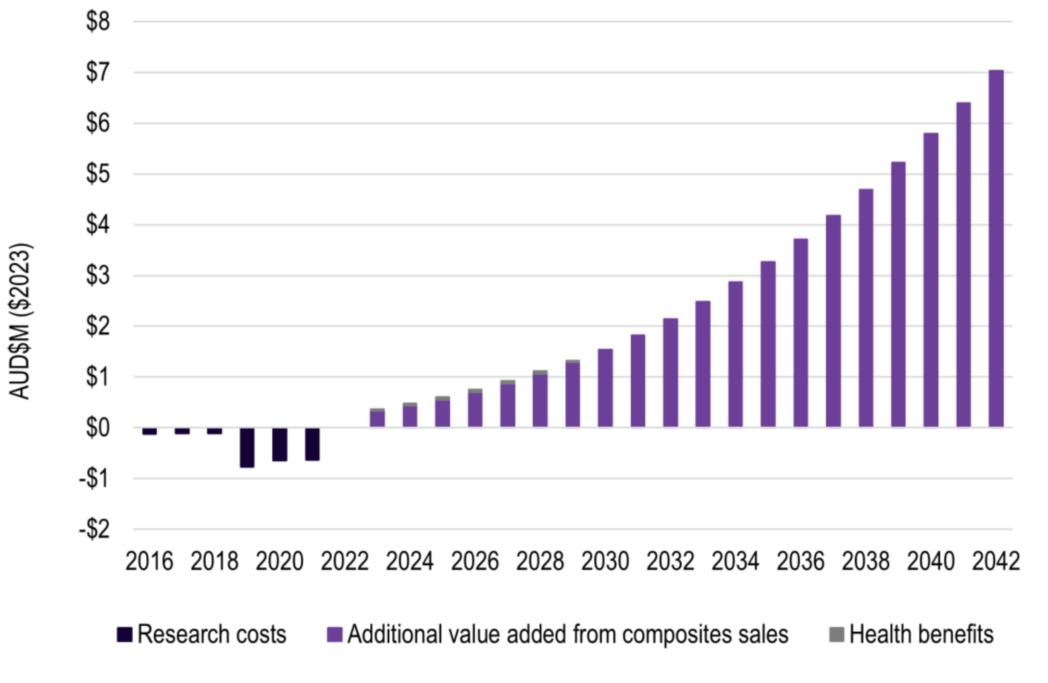

*Source: ACIL Allen.*

### 5.2.3 Net impacts

The costs and benefits to Australia from the SDI-AMAC research collaboration on dental composites to 2042 are shown in Figure 5.9.

[24] Dentino FC et al. (2023). Amalgam or composite in pediatric dentistry: Analysis of private insurance claims data. J Am Dent Assoc. 2023 Aug;154(8):705-714.e10. doi: 10.1016/j.adaj.2023.04.015. PMID: 37500233.

**Figure 5.9** Costs and benefits to Australia from SDI-AMAC research collaboration on dental composites, 2023 to 2042 ($m, 2023 dollars)




*Source: ACIL Allen.*

It is estimated that, under the assumptions outlined above, the SDI-AMAC collaboration would generate (in present value terms in 2023 at 2023 constant prices):

— $23.6 million in additional value added
— $0.3 million in health benefits
— $3.0 million in research costs.

In NPV terms, the overall benefit of the project in 2023 using a 7% real discount rate could be $20.9 million (in 2023 dollars).

The BCR of the project, obtained by dividing the present value of benefits by the present value of costs, is estimated to be 7.90. This means that, for every dollar in research grants invested in the dental composites, AMAC enabled $7.90 in benefits.

### Sensitivity analysis

Given the uncertainty associated with many of the assumptions used in the CBA, sensitivity analysis was conducted to assess the sensitivity of the results to substantial changes in the following assumptions:

— discount rate
— assumed adoption rate of SDI's composites.

The results of the sensitivity analysis are presented in Table 5.3. As shown in this table, the BCR:

— increases with:
  – a reduction in the discount rate
  – an increase in the assumed adoption of SDI's composites by 2042
— decreases with:
  – increases in the discount rate

– decreases in the assumed adoption of SDI's composites by 2042.

However, in all cases, substantial changes to each of the assumptions were not sufficient to result in a BCR of less than one (or a negative net present value).

**Table 5.3** Sensitivity analysis – impact of sensitivity tests on the economy-wide impacts

| | NPV ($M) | BCR |
|---|---|---|
| **Central case** | **$20.9** | **7.9** |
| **Discount rate** | | |
| Decrease from 7% to 3% | $35.7 | 14.5 |
| Increase from 7% to 10% | $14.0 | 5.2 |
| **Changes in adoption of SDI's composites by 2042** | | |
| Reduced adoption by 50% in each market | $10.1 | 4.34 |
| Increased adoption by 50% in all markets, except Australia where adoption is increased to 95% | $44.9 | 15.81 |

*Source: ACIL Allen.*

# Case study: Composite Tanker 6

Road tankers are motor vehicles fitted with tanks designed to carry gases and liquids such as gasoline, diesel, liquefied petroleum, natural gas, and industrial chemicals on roads.[25] Specialised techniques and processes are required to manufacture and maintain these tanks due to the hazardous and volatile nature of the cargo being transported.

**Omni Tank Containers**

*Source: Omni Tanker*

Omni Tanker is a privately held Australian company that designs, develops, and manufactures tank containers and road tanker equipment based on its patented advanced composite materials technology. The company's core focus is to innovate better ways to move and store dangerous and difficult liquids and gasses, improving transport economics and safety, whilst reducing environmental impacts on society. Omni Tanker's equipment is used to transport and store aggressive Class 8 corrosive chemicals in Australia, Europe, and North America.[26]

Omni Tanker and AMAC collaborated on 4 projects which involved developing repair and rework procedures for Omni Tanker, the certification of Omni Tankers' vehicles in the US, the development of a waterjet cutting technique for Omni Tanker parts, and feasibility testing of live structural health monitoring for Omni Tanker's vehicles.

This case study is being undertaken to describe the economic and environmental impacts arising from these projects undertaken by AMAC and Omni Tanker.

This assessment can be read as a standalone report or aggregated with other case studies to substantiate the impact and value of AMAC's work in supporting the next generation of automated composite manufacturing innovations and innovators, and to estimate the return on the investment from the funds spent on these activities.

## 6.1 Impact Framework

Figure 6.1 below provides a high-level overview of the impact pathway of the AMAC and Omni Tanker collaboration.

[25] Inbound logistics. (2024). Tanker Trucks: Types, Capacity, and Safety. https://www.inboundlogistics.com/articles/tanker-trucks/

[26] Omni Tanker. (n.d).About Us. https://omnitanker.com/about-us/

**Figure 6.1** Composite tanker impact pathway

| INPUTS | ACTIVITIES | OUTPUTS | OUTCOMES | IMPACTS |
|---|---|---|---|---|
| – Total funding of $144,271 from Omni Tanker<br>– PhD grant of $31,212 per annum for 3.5 years funded through original ARC grant | – Testing of repair methods that can ensure the high integrity of tanks following process<br>– Testing of waterjet cutting techniques for tanker parts<br>– Investigation of the use of optical fibre technologies for live tanker structural health monitoring (SHM)<br>– Testing of composite materials to collect data on tankers for US certification | – New procedure to join thermoplastics within a tank<br>– Development of a five-axis waterjet profiling manufacture cell<br>– Development of a smart sensing technology using fibre optics for SHM during manufacturing and for the entire life of the product<br>– Material testing to support certification of Omni Tanker's equipment in the US<br>– 3 journal articles<br>– Increased skills and knowledge (one PhD student trained) | – Commercialisation of tanker repair procedures in Australia, EU and US resulting in extended service life<br>– Automated in-house capability to cut tanker parts<br>– Expansion into the US market<br>– Enabling of funding and business opportunities | **Economic**<br>– Increased productivity and efficiency<br>– Increased economic activity and employment<br>– Increased export revenues<br>**Environmental**<br>– Reduced waste from extended life of tankers |

*Source: ACIL Allen, AMAC*

### 6.1.1 Project inputs

Project inputs refer to the resources used/invested in a project to implement it and deliver the intended results. In this case study, this refers to resources invested by AMAC in the composite tanker projects.

AMAC received funding from Omni Tanker for this project in 2018 and 2019 and one PhD student working on these projects was funded through ARC funds for 3.5 years (see Table 6.1).

**Table 6.1** Cash support for the composite tanker project

| Grant Body | Grant Amount | Duration |
|---|---|---|
| Omni Tanker | $144,271 | 2 years (2018-2019) |
| ARC | $109,242 | 3.5 years (2017-2020) |
| **Total** | **$253,513** | |

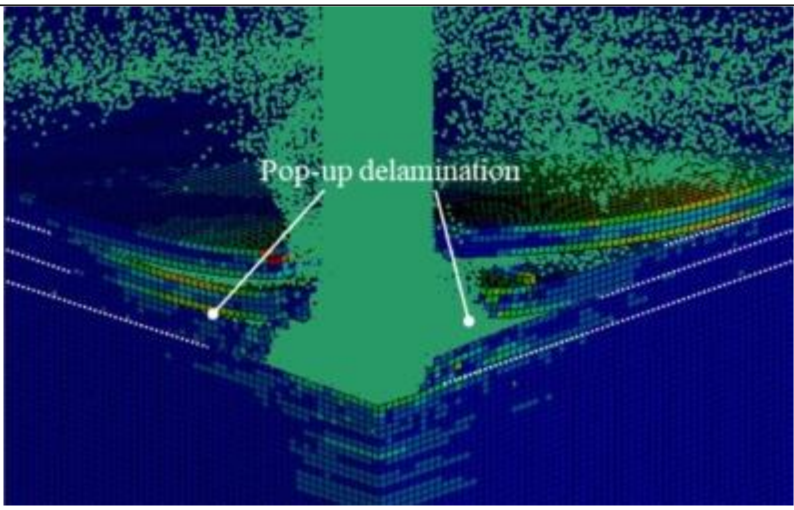
*Source: AMAC*

### 6.1.2 Project Activities

Omni Tanker and AMAC collaborated on 4 projects. A description of these projects and the activities undertaken are provided below.

- *Tanker repair and rework project:* AMAC and Omni Tanker collaborated to develop standardised repair procedures for composite tankers. The highly chemically resistant composite layer inside tankers can be damaged during service. Due to the volatility of the chemicals being transported, tankers require methods that can ensure high integrity following repair. This project involved research on polymers and how to join them with low residual stress to successfully perform repairs.
- *Waterjet cutting of tanker parts:* Omni Tanker found that waterjet cutting caused damage to the composite parts when initiating a cut. Through this project, an AMAC PhD student conducted testing to identify a method of waterjet cutting that would address this issue (see Figure 6.2).

**Figure 6.2** Demonstration of delamination during testing of waterjet cutting on a laminated composite part




*Source:* Gu Y Et al. (2022). Mechanisms of pop-up delamination in laminated composites pierced by the initial pure waterjet in abrasive waterjet machining. https://www.sciencedirect.com/science/article/abs/pii/S0263822322007243#f0055.

- *Tanker live structural health monitoring*: this project investigated the feasibility of using optical fibre technologies for live structural health monitoring (SHM) of tankers on the road. An AMAC PhD student supported this project, which also included the former NSW Roads and Maritime Services, to develop a case study of the use of continuous degree of freedom optical fibres in tanks to undertake real-time structural health monitoring. The particular role of AMAC on this project was to investigate the use of an alternative material as part of the SHM system that would save costs.
- *US road tanker certification project:* although AMAC's involvement in this project was relatively small and towards the end of a broader project, AMAC performed composite materials testing to support Omni Tanker's US road tanker certification process. Through this project, Omni Tanker also collaborated with the US Department of Transportation Volpe Center.

### 6.1.3 Project outputs

The outputs of the composite tanker research project include:

- 3 first-of-a-kind manufacturing technologies
- research to support commercialisation and expansion efforts

— journal articles
— increased skills and knowledge.

These are discussed in more detail in the sections below.

**Manufacturing technologies**

AMAC helped Omni Tanker develop the following 3 major innovations in the production and maintenance of tanks (which are now at various stages of implementation at Omni Tanker's advanced manufacturing facility in Western Sydney)[27]:

— *New procedure to join thermoplastics within a tank* – as part of the tanker repair and rework project, AMAC and Omni Tanker created a new way to join thermoplastics within a tank, which protects its underlying composite layers from damage while maintaining the integrity of the seal.
— *Five-axis waterjet profiling manufacture cell* – the development of a five-axis waterjet profiling manufacture cell. This new method of precision cutting composites uses water pressure and abrasives without the need for manual labour. It is safer, reduces waste and prevents damage to the tanker part. This innovation led to Omni Tanker securing funding through the NSW Government's Manufacturing Modernisation Fund, which was used to incorporate the new technology into production.
— *Smart sensing technology using fibre optics* – the AMAC-Omni Tank collaboration also led to the development of a highly innovative smart sensing technology using fibre optics, which provides structural health monitoring during manufacturing and for the entire life of the product. Fibre optic sensors can be embedded throughout the composite layers of the tank, giving Omni Tanker and its customers comprehensive feedback about any structural damage as soon as it occurs, so it can be addressed quickly, and the potential for more significant damage can be minimised. Omni Tanker noted that this technology has not been commercialised as of May 2024.

**Certification of Omni Tanker's equipment in the US**

Research and data collection undertaken by AMAC supported Omni Tanker to submit data to the US Department of Transport which resulted in certification of Omni Tanker's equipment in the US.

**Journal articles**

The project resulted in 3 journal articles being published.

**Increased skills and knowledge**

This collaboration has resulted in training for one higher degree by research student and 5 postdoctoral fellows at UNSW. At Omni Tanker, several staff were trained on the machining of composites through these projects.

#### 6.1.4 Project outcomes

**Commercialisation of tanker repair procedures in Australia, EU and US**

The procedures and processes to join thermoplastics within a tank developed through the tanker repair and rework project are now used by Omni Tanker in Australia, the EU and the US. Omni Tanker noted that the repair process is now "more refined, standardised and procedural" following

[27] Templeton, L. (2020). UNSW and Omni Tanker find a winning formula in advanced composite manufacturing. https://www.unsw.edu.au/newsroom/news/2020/08/unsw-and-omni-tanker-find-a-winning-formula-in-advanced-composit.

the commercialisation of the research findings. This technology significantly enhances the service life of the tank.

#### In-house, automated capability for cutting tanker parts

Although Omni Tanker noted that the in-house costs of using waterjet cutting and manual techniques are similar, several key benefits of the five-axis waterjet profiling manufacturing cell were highlighted. Firstly, waterjet cutting is an automated process, which frees up valuable skilled labour for use elsewhere in the business. Automation also results in improved work conditions for employees. Further, although most tanker parts are still purchased through a supplier as it is more cost-effective, the in-house capability allows for reactive repairs when a client requires a new part with a fast turnaround.

#### Expansion of Omni Tanker into the US market

AMAC contributed to the certification of Omni Tanker's road tankers in the US through composite materials testing. Omni Tanker is now approved with units in operation in the US since 2020.

#### Enabling funding and business opportunities

Omni Tanker noted that the collaborations with AMAC have contributed to further funding opportunities and could lead to business opportunities in the future.

Omni Tanker noted that they reference work completed with AMAC in grant applications which contributes to their overall proposals. Although Omni Tanker's applications include examples from a broad range of collaborators, the AMAC collaborations are still a contributing factor to the strength of the overall application. Omni Tanker has received a Global Innovations Linkages grant and a grant from Lockheed Martin following the AMAC collaboration.

Further, the collaboration with AMAC has facilitated Omni Tanker's involvement in the ACM CRC. In October 2023, ACM CRC announced a project with Omni Tanker to create a "digital twin" of its pilot production plant, a move that marks a significant leap towards optimising composites manufacturing.

Omni Tanker also noted that the journal papers developed as part of the collaboration could be used in future marketing and proving out of technologies by the business. Omni Tanker stated that journal papers highlight the business' knowledge and experience in a particular area. Omni Tanker has used journal articles in the past to open business development opportunities, for example, by demonstrating the positive scientific outcomes of the technology or in exchanges with international governments to receive approvals. Omni Tanker has not yet used the journal papers developed through the AMAC collaboration but expects to do so in future.

### 6.1.5 Project impacts

#### Economic

The 3 economic benefits identified through this research collaboration are:

- avoided costs from the extended life of tankers
- increased revenue from the expansion of Omni Tanker into the US market
- more efficient use of skilled labour through automated waterjet cutting.

Omni Tanker noted that the repair and rework procedures will lead to the extended useful life of their tanks in Australia, the US and the EU. Omni Tanker noted that at this stage it is difficult to estimate the number of years that the procedures will extend the life of the tankers, and that it would depend on the aggressive nature of the chemicals being transported.

A further benefit of the collaboration is the expansion of Omni Tanker into the US market following the certification of their equipment. To provide an indication of the scale of the US market, Omni Taker estimated the total assessable market for tanker sales in the US to be USD$750 million per annum.[28] This opens up significant business opportunities for Omni Tanker (benefits specifically for the corrosive chemical tanker market are estimated in Section 6.2.2).

Finally, the commercialisation of the waterjet cutting techniques at Omni Tanker has resulted in automating a process that was undertaken manually by skilled labour at Omni Tanker. This increases the overall efficiency of the business and could lead to freed-up labour contributing to additional revenue streams.

**Environmental**

Omni Tanker noted that part of its value proposition to the market is through its Environmental, Social and Governance (ESG) mission. For example, Omni Tanker noted that their tankers result in a 5-10% payload uplift compared to other tankers on the market, which reduces fuel use[29] and thus greenhouse gas emissions. Extending the useful life of the tankers through improved repair and rework procedures would also result in less waste and resource usage by delaying the replacement of tankers in the fleet.

### 6.1.6 Clarifying the impacts

When estimating the impacts of AMAC's research, ACIL Allen must ensure that the benefits and costs counted in the analysis are compared against the baseline scenario. This scenario estimates the trajectory of outcomes in a world where AMAC did not undertake the research project. For the estimation of impacts, it is assumed that Omni Tanker would not have succeeded in entering the US market without the findings from the research collaboration with AMAC.

**Attribution**

Attribution represents the extent to which AMAC enabled impacts that have occurred because of this collaborative project. Benefits from the research project must be adjusted for attribution to AMAC to acknowledge the important work of other parties involved in the research collaboration. Omni Tanker has provided an estimate of 5% for the attribution of the listed project impacts to AMAC.

## 6.2 Estimated Impacts

As discussed in section 4.2, we have used a CBA framework to assess the value delivered by the AMAC-Omni Tanker collaboration. According to Omni Tanker, of the 4 collaborative research projects undertaken, findings from 3 of the projects have been commercialised. Those 3 projects were the tanker repair and rework project; the US road tanker certification project; and the waterjet cutting of tanker parts project. A range of benefits are derived from these projects, as discussed in Section 6.1.5.

Noting the commercial sensitivities of these projects, the impacts estimated in this section are based on broad figures on the US tanker market supplied by Omni Tanker. We have assessed the potential benefits of the AMAC-Omni Tanker collaboration using these figures and publicly available information.

[28] This is based on an estimate of approximately 5000 tankers sold in the US at a unit price of USD$150,000. Source: Omni Tanker

[29] This would also result in cost savings for businesses, which have not been estimated due to commercial sensitivities of the Omni Tanker fleet.

The following sections outline the costs and benefits captured in the analysis.

### 6.2.1 Costs

As outlined in Table 6.1 the nominal research costs of the AMAC-Omni Tanker collaboration totalled $253,513 incurred between 2017 and 2020 (equivalent to $299,098 in 2023 prices).

The present value (PV) in 2023 of these costs using a 7% real discount rate is $333,806 (in 2023 dollars). It has been assumed that research funds were distributed equally during every year of the grant.

### 6.2.2 Benefits

As noted above, given commercial sensitivities, Omni Tanker was only able to provide information regarding AMAC's contribution to Omni Tanker's expansion into the US market.

Omni Tanker highlighted the following projects undertaken by AMAC which contributed to Omni Tanker's market expansion into the US in 2020:

— development of repair and rework technologies
— exploratory characterisation of composite materials for tank structures as part of the US road tanker project
— advanced waterjet cutting techniques.

Omni Tanker noted that these efforts contributed to them being able to directly target the US corrosive chemicals market segment with a value of approximately USD$60 million per annum (equivalent to around AUD$88 million per annum).

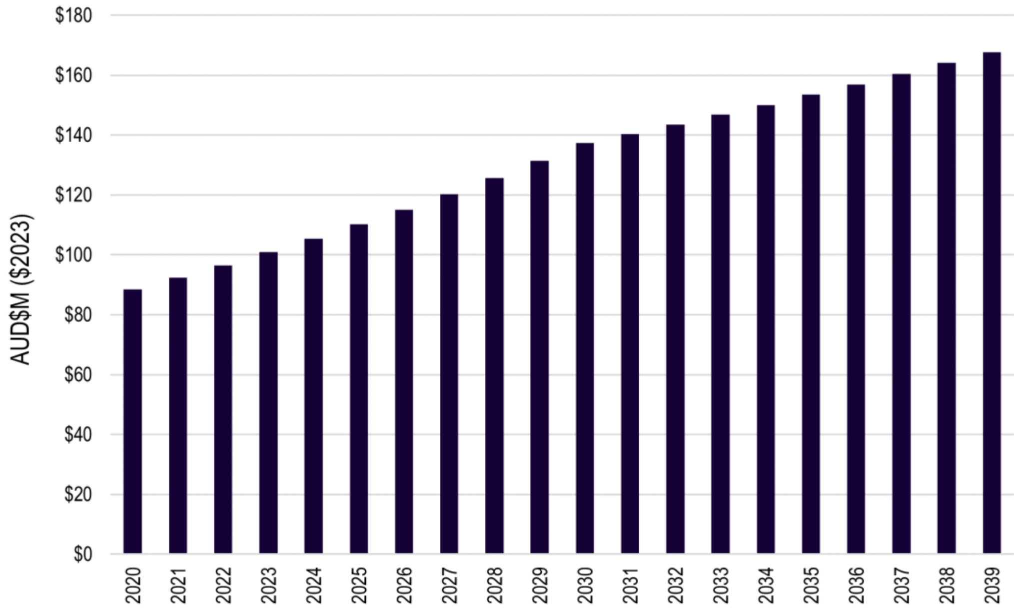
The expansion to the US market is likely to contribute to higher levels of economic activity through increased revenue to Omni Tanker, purchasing of higher value input materials and employment opportunities (tanks are manufactured in NSW and shipped to the US).

Assuming that the corrosive chemical tank market in the US grows at a CAGR of 4.5% between 2020 and 2030 and at a CAGR of 2.3% thereafter through to 2039 [30] [31], this market could reach USD$114 million in 2039 (equivalent to approximately AUD$168 million, see Figure 6.3).

[30] Skyquest. (2024). Chemical Tanker Market Insights, Accessed May 2024: https://www.skyquestt.com/report/chemical-tanker-market#:~:text=Chemical%20Tanker%20Market%20Insights,period%20(2024%2D2031).

[31] The Business Research Company. (2024) Chemical Tankers Global Market Report.: https://www.thebusinessresearchcompany.com/report/chemical-tankers-global-market-report

**Figure 6.3** Estimated market for corrosive chemical tanks, 2020 to 2039 ($m, $2023)

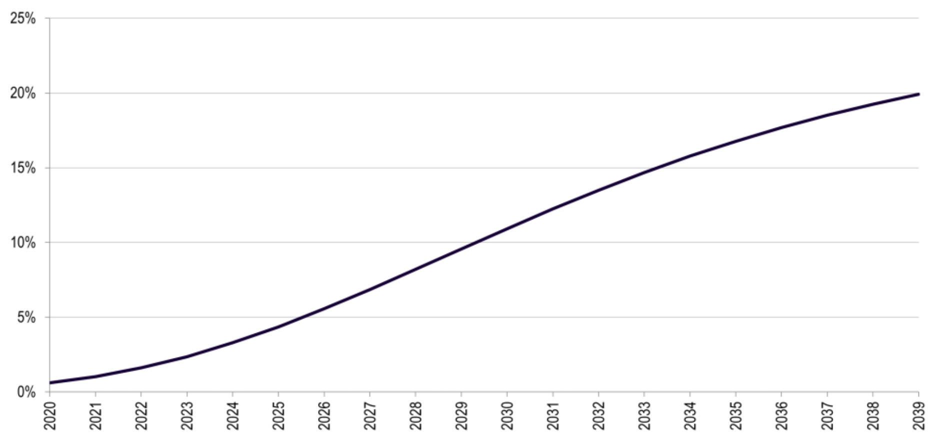



*Source: ACIL Allen, The Business Research Company, Skyquest*

The potential benefits to Australia from adoption of Omni Tanker's tanks in the US enabled through AMAC research (in terms of value added) were assessed based on:

— the market estimates in Figure 6.3
— assumptions about the adoption of Omni Tanker's tanks in the US market (shown in Figure 6.4). We have assumed that Omni Tanker's tanks achieve a market share by the end of the projection period (2039, 20 years from the year that the technology went to market) of 20%
— the following assumptions:
  – that value added by the boiler and tank manufacturing industry represents around 40% of its revenue
  – that, as discussed in Section 6.1.6, 5% of the benefits generated by Omni Tanker's expansion to the US were enabled/can be attributed to AMAC's research.

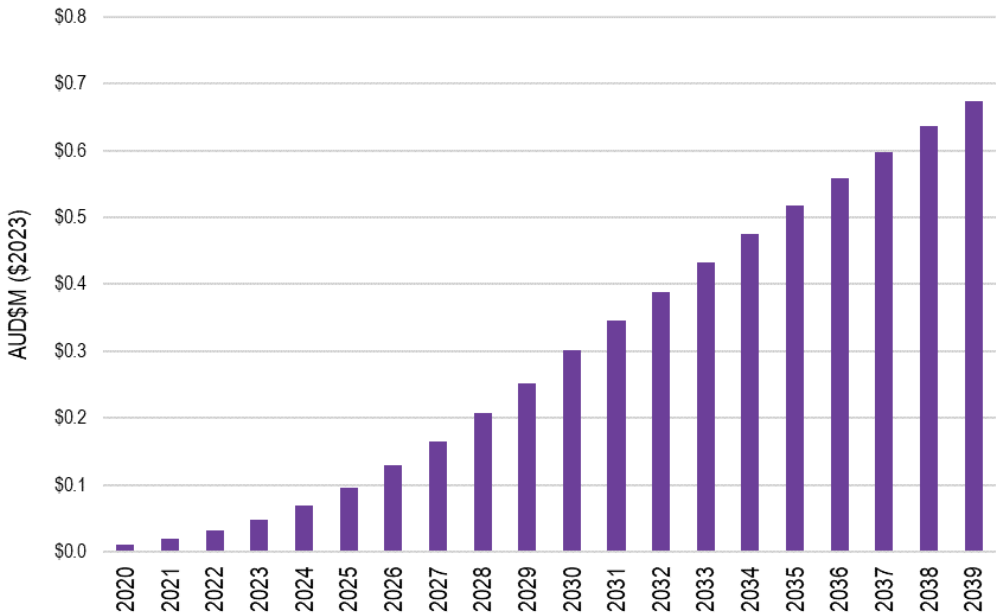
**Figure 6.4** Assumed adoption of Omni Tanker's tankers in the US market




*Source: ACIL Allen.*

The potential benefits to Australia of the research collaboration undertaken by AMAC over the period 2020 to 2039 are shown in Figure 6.5. The present value in 2023 of these benefits using a 7% real discount rate is $3 million (in 2023 dollars).

**Figure 6.5** Potential benefit to Australia from sales of Omni Tanker tanks in the US derived from AMAC's research, 2020 to 2039 ($m, 2023 dollars)

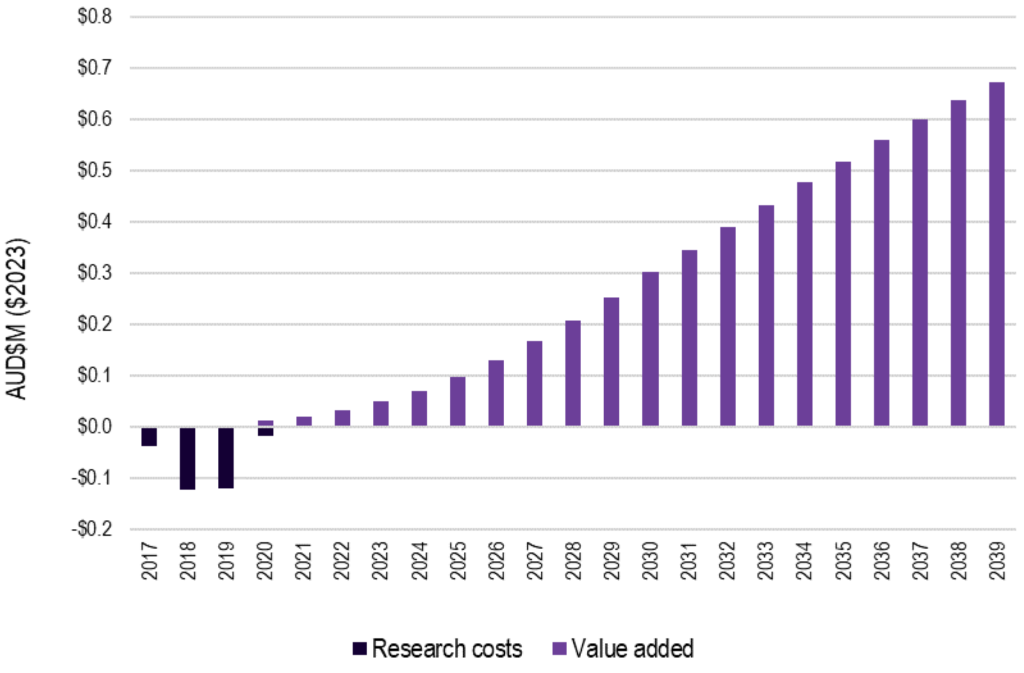



*Source: ACIL Allen*

### 6.2.3 Net impacts

The costs and benefits to Australia from the AMAC-Omni Tanker research collaboration are shown in Figure 6.6.

**Figure 6.6** Costs and benefits to Australia from AMAC-Omni Tanker research collaboration, 2018 to 2039 ($m, 2023 dollars)




*Source: ACIL Allen*

It is estimated that, under the assumptions outlined above, the AMAC-Omni Tanker collaboration would generate (in present value terms in 2023 at 2023 constant prices) approximately $3 million in value added.

In NPV terms, the net benefit of the project in 2023 using a 7% real discount rate, could be $2.7 million (in 2023 dollars).

The BCR of the project is estimated to be 9.0, meaning that for every dollar in research grants invested by AMAC into the composite tanker research, AMAC may enable $9 in benefits.

**Sensitivity Analysis**

Given the uncertainty associated with many of the assumptions used in the CBA, sensitivity analysis was conducted to assess the sensitivity of the results to substantial changes in the following assumptions:

— discount rate
— assumed adoption of Omni Tanker's tanks in the US corrosive chemical market.

The results of the sensitivity analysis are presented in Table 6.2. As shown in the table, the BCR:

— Increases with:
  – a reduction in the discount rate due to the time value of money (i.e. a dollar today is worth more than a dollar tomorrow)
  – an increase in the assumed adoption of Omni Tanker's tanks in the US corrosive chemical market
— Decreases with:
  – an increase in the discount rate
  – a decrease in the assumed adoption of Omni Tanker's tanks in the US corrosive chemical market.

In all cases, substantial changes to the assumptions were not sufficient to result in a BCR of less than one (or a negative NPV).

**Table 6.2** Sensitivity analysis – impact of sensitivity tests on the economy-wide impacts

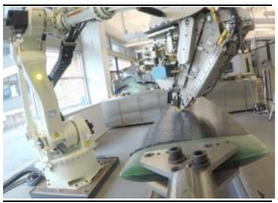
| | NPV ($M) | BCR |
|---|---|---|
| **Central case** | **$2.7** | **9.0** |
| **Discount rate** | | |
| Decrease from 7% to 3% | $4.1 | 13.9 |
| Increase from 7% to 10% | $2.0 | 6.7 |
| **Changes in adoption of Omni Tanker's tanks in the US by 2039** | | |
| Reduced adoption by 50% (from 20% to 10%) | $1.2 | 4.7 |
| Increased adoption by 50% (from 20% to 30%) | $4.1 | 13.3 |

*Source: ACIL Allen.*

# Case study: Composite Propeller Blade 7

Composite materials have the potential to improve marine propulsion efficiency through the creation of adaptive pitch marine propellers. The adoption of automated manufacturing technologies, particularly AFP, offers a unique avenue for producing parts with curved fibre paths, a production method that has not been thoroughly explored previously.

**Propeller blades made at AMAC**



*Source: AMAC*

The Defence Science Technology Group (DSTG) was a founding partner of AMAC from 2017 and the Platforms Division has invested and engaged extensively in AMAC research in advanced composites including automation, thermoplastics, performance assessments, fibre optic sensors, simulation and production of a composite propeller blade. This propeller blade provides enhanced pitch adaptability features and increases strength and deflection limits, leading to improvements in propulsion efficiency.

Further, AMAC in conjunction with DSTG has produced studies focussing on developing the tools and knowledge required to manufacture adaptive propellers with embedded sensors using the AFP method. These sensors collect data on the status of the propeller blade and can be used to monitor its condition. AMAC has also developed simulation models to understand how impact damage affects composite marine propellers and the effects of moisture uptake on performance.

This case study describes the potential future economic and environmental benefits that could arise from the AMAC-DSTG collaboration. In particular, it assesses the potential benefits of the adoption of the shape adaptive marine propeller by defence vessels.

This evaluation is being undertaken to assess the impacts arising from projects undertaken by AMAC. This case study can be read as a standalone report or aggregated with other case studies to substantiate the impact and value of AMAC's work in supporting the next generation of automated composite manufacturing innovations and innovators, and to estimate the return on the investment from the funds spent on these activities.

## 7.1 Impact Pathway

A high-level impact pathway for AMAC's project on composite marine propellers is summarised in Table 7.1.

**Figure 7.1** Composite marine propeller impact pathway

| INPUTS | ACTIVITIES | OUTPUTS | OUTCOMES | IMPACTS |
| --- | --- | --- | --- | --- |
| – Cash support from DSTG grants<br>– AMAC research expertise in automated manufacturing technologies, particularly AFP<br>– AMAC's AFP robot<br>– Expertise from the DSTG Platforms Division | – Research and development of tools and processes to manufacture adaptive propellers with embedded sensors<br>– Developing simulation models to assess durability of composites propeller blades | – Fabrication of scaled and full-scale hydrofoils and pitch adaptive propeller blades<br>– Journal articles and conference presentations<br>– Increased skills and knowledge (2 PhD students trained) | – Research may enable future large-scale manufacturing of 'intelligent' shape-shifting propeller blades that monitor their own performance and adapt to changing conditions in the water<br>– JEC Asia (Korea) award 2019<br>– Opportunities for potential strategic engagement with external parties | **Economic**<br>– Human capital formation<br>– Potential cost savings through increase in naval vessels fuel efficiency<br>– Potential for improved longevity of naval vessels propellers and drive shafts<br>**Environmental**<br>– Potential reduction in emissions from naval vessels<br>– Potential reduced waste from extended life of propellers and drive shafts<br>**Social**<br>– More effective national defence from reduced noise generation and the absence of a detectable "magnetic signature" from a composite propeller |

*Source: ACIL Allen, AMAC*

### 7.1.1 Project inputs

Project inputs refer to the resources used/invested in a project to implement it and deliver the intended results. In this case study, this refers to resources invested by AMAC in the composite propeller project.

AMAC received funding for this project from the ARC and DSTG (see Table 7.1).

**Table 7.1** Cash support for the composite propeller blade project

| Grant Body | Grant Amount | Duration |
| --- | --- | --- |
| ARC | $190,000 | 5 years (2017-2021) |
| DSTG | $870,000 | 4 years (2016-2019) |
| **Total** | **$1,060,000** | |

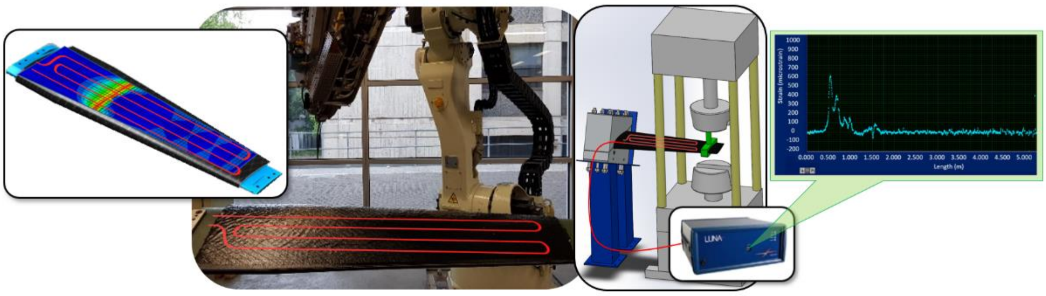
*Source: AMAC*

### 7.1.2 Project activities

AMAC undertook 2 significant activities through this research collaboration. The first activity focused on developing the tools and knowledge required to manufacture propellers with embedded sensors using AFP. AFP produces more consistent and higher quality structures compared to existing composite manufacturing technologies thereby improving safety. Integrated/embedded sensors allow for the detection of faults or damage during manufacturing and operation, prompting early repairs as well as the production of consistent and reliable high-quality structures.[32] DSTG stated that a key aim of this engagement was to conduct research with universities through PhD programs and to gain knowledge through researcher exchanges with French institutions. AMAC brought a considerable amount of expertise and knowledge on composite manufacturing, including AFP, which DSTG saw was highly valuable to the collaboration.

The second activity was the development of simulation models to assess the underwater impact and damage development of composites. Sensors were embedded into the AFP fabricated components to monitor changes in the composite propeller blades, including component stress from moisture and temperature as well as changes occurring during impact events. Impact testing of the composite material was conducted in France and Australia, and a UNSW student engaged through AMAC developed a new non-destructive testing technique to inspect impacts (see Figure 7.2). In addition to examining the underwater impact performance of composites, other tests were also conducted, such as examining the role of crystallinity on the variation of characteristics in thermoplastic composites due to seawater ageing.

**Figure 7.2** Structural testing of composite propeller blades



*Source: AMAC*

DSTG stated that partnering with AMAC through both collaborations was beneficial and contributed to the critical issue of workforce development in the advanced manufacturing space. DSTG appreciated the level of engagement through AMAC and has employed one of the PhD students involved in the collaboration.

### 7.1.3 Project outputs

The outputs of the composite propeller project include:

— new application of composite material for use in pitch adaptive propeller blades

— journal articles and conference presentations

— increased skills and knowledge.

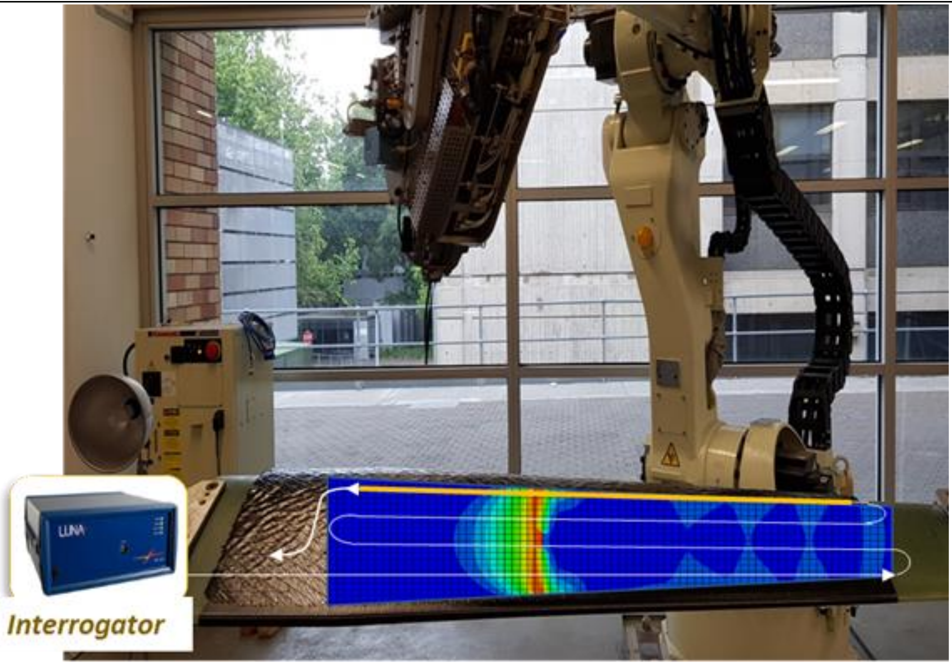
These are discussed in more detail in the sections below.

[32] SoMAC. (2021). The SoMAC CRC prospectus. https://advanced-composites.co/wp-content/uploads/2021/02/The-SoMAC-CRC-Prospectus-20210208c-Appendix.pdf

### New application of composite material

AMAC designed and manufactured a 1.35 metre-long composite hydrofoil propeller blade using AFP. The hydrofoil design comprised of 2 main components – the 'core' and the 'skin'. The core is made of glass-fibre/epoxy to minimise manufacturing costs, whereas, the 'skin', is a 96-layer carbon/epoxy prepreg laminate wrapped around the core using AFP. The AFP manufacturing process allowed tailored stiffness to be introduced to the passive shape-adaptive material, whilst the integrated optical fibre sensors allowed monitoring of operational performance (see Figure 7.3).

**Figure 7.3** Hydrofoil propeller blade with embedded sensors




*Source: AMAC*

### Journal articles, conferences and awards

Table 7.2 summarises the AMAC's publications and conferences over the period 2017-2022.

**Table 7.2** AMAC's publications and conferences

| Category | Number |
|---|---|
| PhD thesis produced | 3 |
| ME/BE thesis produced | 3 |
| Journal articles published | 11 |
| Conference presentations | 5 |

*Source: AMAC*

Through the AMAC and DSTG collaboration 3 PhD and 3 ME/BE theses were produced, 11 journal articles were published, and 5 conference presentations were given, providing multiple intangible benefits to society and to AMAC. These outcomes are likely to:

— Contribute to extending other researchers' access to existing knowledge and may have a multiplier effect on advancements in marine composites manufacturing.

— Raise the profile of participants' research which may lead to future collaboration and grant opportunities. Increased levels of funding may also be received due to improved academic reputation and history of success engaging in industry collaborations.

— Contribute to the overall university rankings, which may lead to higher levels of student enrolment, grant funding received and academic collaboration with external entities.

**Increased skills and knowledge**

DSTG noted that the COVID-19 pandemic affected opportunities for AMAC PhD students and researchers to travel between Australia and France to work on projects in person. Despite this, the project resulted in the successful training of 3 PhD students and 4 post-doctoral researchers, and the development of a novel test setup for underwater impact testing equipment and durability testing procedures for composite propellers.

### 7.1.4 Project outcomes

A key outcome of the AMAC-DSTG collaboration is that the research may enable future large-scale manufacturing of 'intelligent' shape-shifting propeller blades that monitor their own performance and adapt to changing conditions in the water. The use of fibre reinforced plastic makes the propeller blade significantly lighter than alternatives and combined with the shape-adaptive design, reduces fuel consumption significantly for maritime vessels. Furthermore, composites also have high resistance to fatigue and corrosion, leading to longer life cycles of the component.[33]

The research also resulted in the awarding of the 2019 JEC Asia Innovation Award to AMAC in the marine category for the full-scale hydrofoil design with embedded optical fibre sensors.[34] The JEC Innovation Awards is a worldwide program that aims to identify, promote and reward innovative composite solutions. By winning the award, AMAC staff were presented with the opportunity to network with a range of high performing international researchers in the advanced composites manufacturing space and promote the work of AMAC and UNSW. Furthermore, this award recognises the high quality and innovative nature of AMAC's research and promotes the composite propeller design to industry, academia and government sectors.

Another outcome of the project was international collaborations with the French Direction générale de l'armement and the Institut Français de Recherche pour l'Exploitation de la Mer (IFREMER) oceanographic institute. This collaboration provided DSTG and AMAC with the opportunity to further develop science and technology capability that may not otherwise have been available in Australia.

### 7.1.5 Project impacts

**Economic**

A key impact of AMAC's collaboration with DSTG has been human capital formation through the training provided to PhD students and a post-doctoral student. According to DSTG, the AMAC centre has contributed to workforce development by providing industry-ready PhDs who can quickly integrate into advanced composite manufacturing enterprises and contribute to business generation. This has contributed to developing a more productive and innovative workforce in Australia.

In addition, while currently the composite propeller produced by AMAC does not possess a technology readiness level high enough for applications in defence, it is possible that in the future,

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[33] SoMAC. (2021). The SoMAC CRC prospectus. https://advanced-composites.co/wp-content/uploads/2021/02/The-SoMAC-CRC-Prospectus-20210208c-Appendix.pdf

[34] UNSW. (2019). UNSW researchers awarded for innovative marine propeller blade. https://www.unsw.edu.au/newsroom/news/2019/11/unsw-researchers-awarded-for-innovative-marine-propeller-blade

advanced composite propellers could be fit to existing and future naval vessels. The potential benefits of this could include:

— *Improved longevity of naval vessel propellers and drive shafts, and reduced sustainment costs*: composite propeller blades are not only more resistant to corrosion relative to nickel, aluminium and bronze (NAB) propellers, but also are more resistant to impact damage due to the malleable nature of the material. This results in reduced damage to the propeller and drive shaft from strikes. Structural health monitoring may also contribute to extending propeller life by providing real time updates on the integrity of the propellers. The improved longevity of the propellers and the reduced number of manual inspections due to the inbuilt sensors are expected to result in reduced sustainment costs.
— *Cost savings through an increase in fuel efficiency*: the lightweight nature of the composite propellers and pitch adjustable design of the blades could increase the fuel efficiency of naval vessels. The composite propeller design provides a 75%[35] weight reduction relative NAB materials, which combined with the shape and behaviour of the composite material could improve the fuel economy of vessels.
— *Reduced noise and vibration:* the composite materials may reduce the noise and vibration of vessels relative to NAB propellers, providing operational advantages.

**Environmental**

If composite propeller designs are adopted by naval vessels, this could contribute to reducing the overall diesel requirement of ships, reducing total greenhouse gas emission per kilometre of vessel operation. In addition, the AFP process used to lay composite materials during the manufacturing process is efficient, improves quality and reduces the waste material produced. Smart monitoring via fibre optic sensors could reduce the frequency of physical inspections reducing the carbon footprint of inspections throughout the lifecycle.

**Social**

Adopting composite propeller blades in naval vessels may also result in more effective national defence. Compared to NAB propellers composite propellers produce less noise and do not have a detectable “magnetic signature”.[36] This mean that composite propeller blades would reduce the likelihood of naval vessels being detected which provides advantages in defence applications.

### 7.1.6 Clarifying the impacts

When estimating the impacts of AMAC’s research, ACIL Allen must ensure that the benefits and costs counted in the analysis are compared against the ‘baseline scenario’. This scenario estimates the trajectory of outcomes in a world where AMAC did not undertake the research project. The base case scenario for this project assumes that naval vessels would continue to utilise NAB propellers in the absence of the research into the composite marine propeller blade. The research focused on the adoption of automated manufacturing technologies and the use of inbuilt sensors which have not been thoroughly explored previously, thus the CBA assumes that it would not be possible for these propellers to have been developed under the baseline scenario in the absence of the collaboration.

[35] SoMAC. (2021). The SoMAC CRC prospectus. https://advanced-composites.co/wp-content/uploads/2021/02/The-SoMAC-CRC-Prospectus-20210208c-Appendix.pdf

[36] UNSW. (2019). UNSW researchers awarded for innovative marine propeller blade. https://www.unsw.edu.au/newsroom/news/2019/11/unsw-researchers-awarded-for-innovative-marine-propeller-blade

#### Attribution

Attribution represents the extent to which AMAC enabled impacts that have occurred because of the project. Benefits from the research project must be adjusted for attribution to AMAC to acknowledge the important work of other parties involved in the research collaboration. AMAC's attribution has been estimated at 35% based on advice from AMAC and DSTG.

## 7.2 Estimated impacts

Please note that the estimates in this section have been developed by ACIL Allen as an illustrative example of the future impacts that might be enabled by this research project if the technology is successfully commercialised. While these estimates provide an indication of the size of the opportunity for this technology, they do not quantify the specific benefits that would be captured by AMAC and/or AMAC's partners.

Due to the sensitive nature of the research and the work undertaken by DSTG, ACIL Allen has drawn on publicly available information to develop this analysis.

As discussed in section 4.2, we have used a CBA framework to assess the value delivered by the AMAC-DSTG collaboration. The following sections outline the costs and benefits captured in this analysis.

### 7.2.1 Costs

As outlined in Table 7.1, the nominal research costs of the AMAC-DSTG collaboration totalled $1,060,000 incurred between 2016 and 2021 (equivalent to $1.27 million in 2023 prices).

The present value (PV) in 2023 of these costs using a 7% real discount rate is $1.81 million (in 2023 dollars). It has been assumed that research funds were distributed equally during every year of each grant.

### 7.2.2 Benefits

As noted before, the composite propeller designed under this partnership is a prototype and there are currently no plans to operationalise this across the Royal Australian Navy (RAN or the Navy). However, AMAC researchers anticipate that if the work on this project continues, then the composite propellers could be out in the market in 10 years. In light of this, we have estimated 2 potential benefits associated with the adoption by the RAN of composite propellers developed through the AMAC-DSTG collaboration:

- Reduction in expenditure on fuel by the Navy due to efficiency gains from the use of composite propellers over NAB propellers.
- Reduction in sustainment costs for Navy vessels due to reduction in impact damage of composite propellers, reduction in manual labour costs from inspection and extended life of composite propellers relative to NAB propellers.

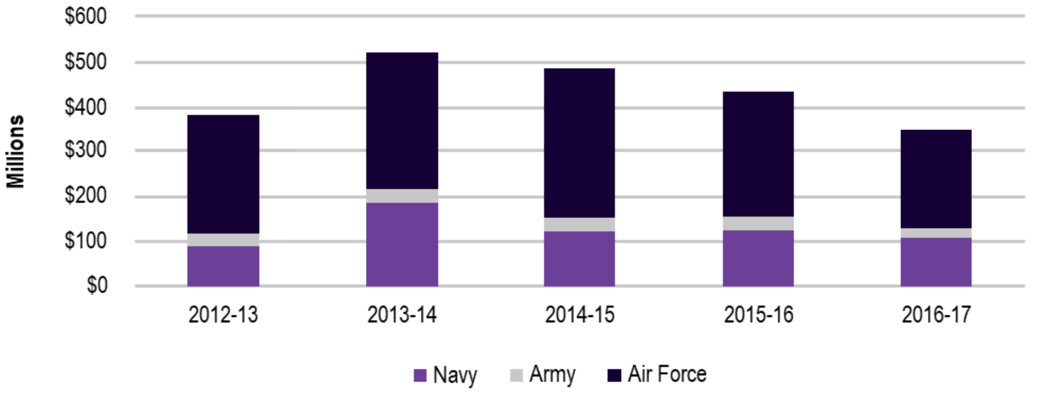
These benefits are discussed in more detail below.

#### Fuel savings

The Department of Defence does not regularly publish fuel consumption or cost data. However, a 2018 report by the Australian National Audit Office (ANAO) on Defence's fuel procurement provided some data on fuel costs. This report noted that 'Fuel is Defence's largest single commodity expenditure' and that there is 'an annual spend on fuel of approximately $423 million' [37] The report also provided a breakdown of spending on fuel between Defence's services (see Figure 7.4) and noted that over the period 1 July 2012 to 30 June 2017 Defence spent $2.1 billion on fuel and lubricants, including:

— $630 million by the Navy (around 29% of the total cost of fuel)
— $139 million by the Army (approximately 6% of the total cost of fuel)
— $1.4 billion by the Air Force (around 65% of the total cost of fuel).

**Figure 7.4** Total cost of fuel, by Service, 1 July 2012 to 30 June 2017 ($m)




*Source: ANAO 2018, Defence's procurement of fuels, petroleum, oils, lubricants and card services, performance audit report, no. 28, 2017–2018.*

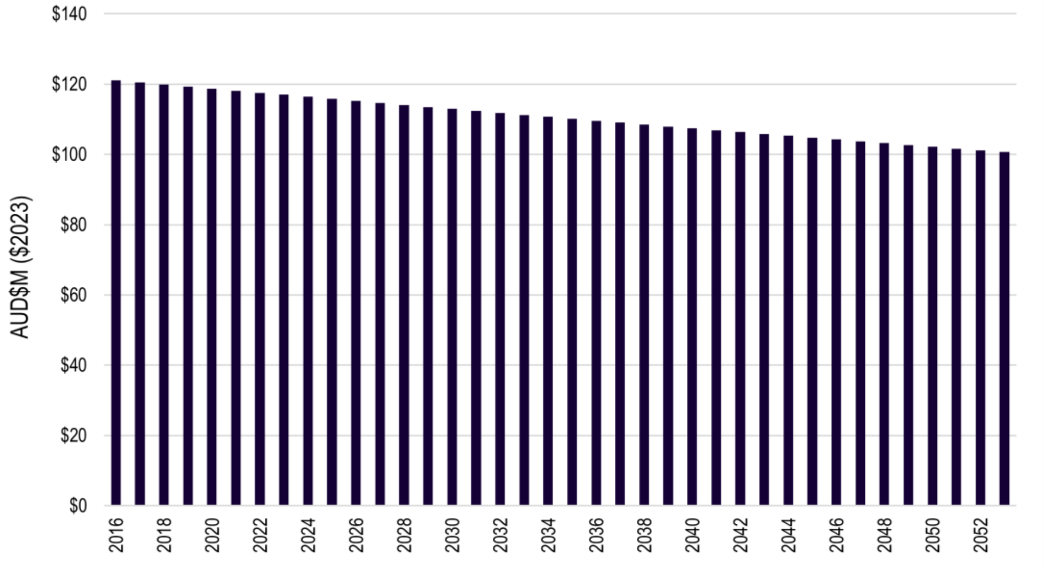
To model the potential benefits of the composite propeller technology, we estimated an indicative annual spend on fuel by the Navy using the information above and the following assumptions:

— Defence's expenditure on fuel in 2016 was $423 million (assumed to be in 2016 dollars), equivalent to $521 million in 2023 dollars. Around 29% of this expenditure ($151 million in 2023 dollars) corresponds to the Navy.
— Around 80% of the Navy fuel costs relate to vessels where the composite propeller could be potentially adopted (i.e. approximately $121 million in 2016).
— Reflecting technological change and measures to improve the energy efficiency of ships, it is assumed that there is an annual fuel efficiency of 0.5% under the baseline scenario (i.e. the costs of fuel decrease by 0.5% per annum).

This results in the costs of Navy vessels totalling around $101 million in 2053 (in 2023 dollars) – see Figure 7.5.

[37] Australian National Audit Office (ANAO). (2018). Defence's procurement of fuels, petroleum, oils, lubricants and card services, performance audit report, no. 28, 2017–2018. https://www.anao.gov.au/work/performance-audit/defences-procurement-fuels-petroleum-oils-lubricants-and-card-services.

**Figure 7.5** Estimated cost of fuel by Navy vessels, 2016 – 2053 ($m, 2023 dollars)

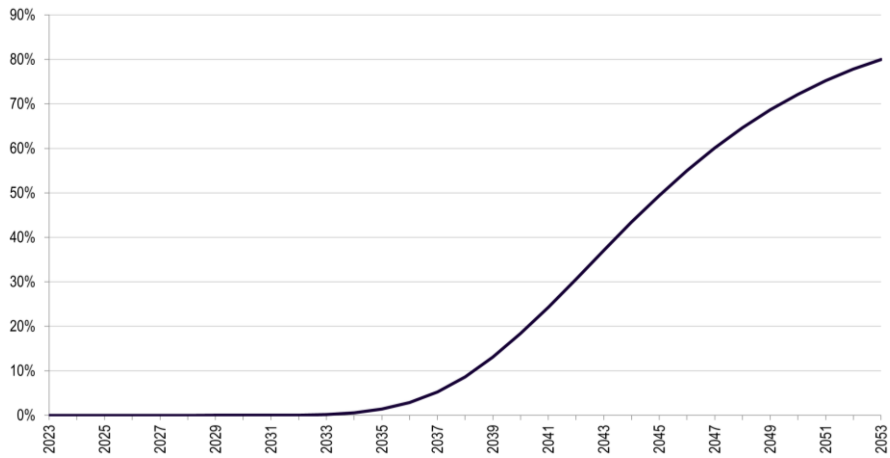



*Source: ACIL Allen*

The potential fuel savings to Defence from adoption of composite propellers in Navy vessels enabled through AMAC research were assessed based on:

— the fuel cost estimates in Figure 7.5
— the following assumptions:
  – a composite propeller based on AMAC's prototype is available in the market from 2034
  – that 80% of Navy vessels use composite propellers based on AMAC's prototype by the end of the projection period (2053, 20 years from the year that the technology is assumed to go to market – see Figure 7.6)
  – that composite propellers result in a reduction in fuel consumption of 1.5% (compared to current RAN propellers)[38]
  – that, as discussed in Section 7.1.6, 35% of the benefits generated by the composite propeller were enabled/can be attributed to AMAC's research.

**Figure 7.6** Assumed adoption of composite propellers in Navy vessels

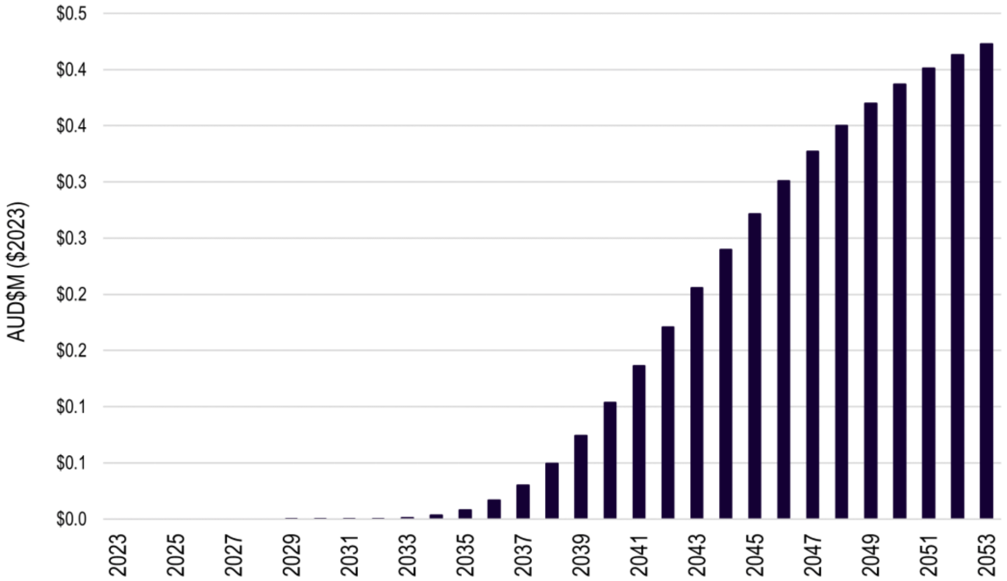



*Source: ACIL Allen.*

[38] This assumption was informed by discussions with DSTG and AMAC.

The potential fuel savings for the Navy as a result of the AMAC-DSTG research collaboration over the period 2023 to 2053 are shown in Figure 7.7. The present value in 2023 of these benefits using a 7% real discount rate is $0.85 million (in 2023 dollars).

**Figure 7.7** Potential fuel savings for the Navy as a result of adoption of composite propeller derived from AMAC's research, 2023 to 2053 ($m, 2023 dollars)




*Source: ACIL Allen*

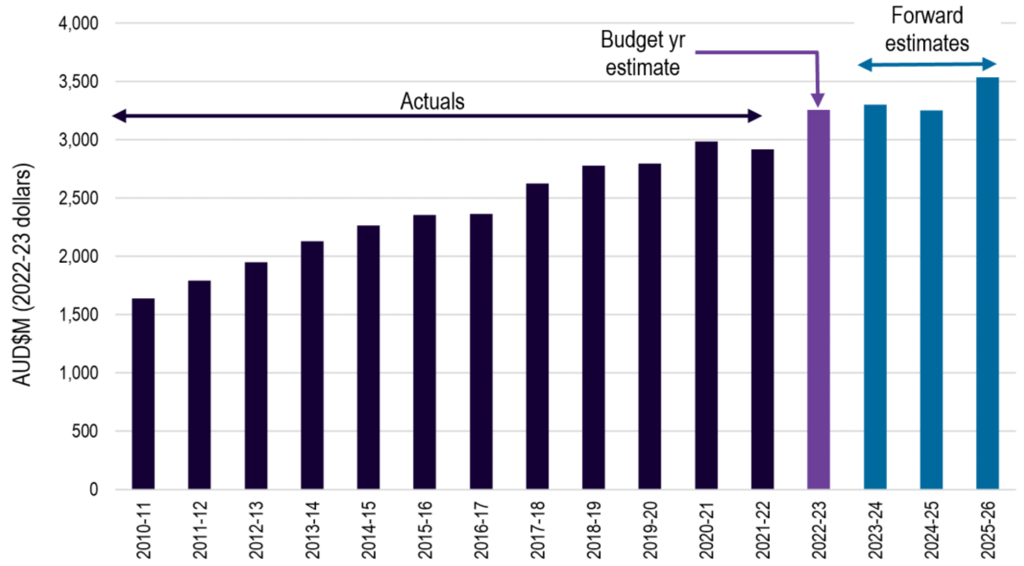
### Sustainment cost savings

Information about Defence sustainment costs was sourced from the Cost of Defence Public Database by the Australian Strategic Policy Institute (ASPI)[39]. This database provides (in real 2022-23 dollars, see Figure 7.8):

— actual data on sustainment costs by the Navy from 2010-11 to 2021-22
— budget estimates for 2022-23
— forward estimates for 2023-24 to 2025-26.

[39] See: https://www.aspi.org.au/cost-of-defence-database. ASPI derives the data in this database from a range of official sources.

**Figure 7.8** Navy sustainment spending, 2010-11 to 2025-26 ($m, 2022-23 dollars)



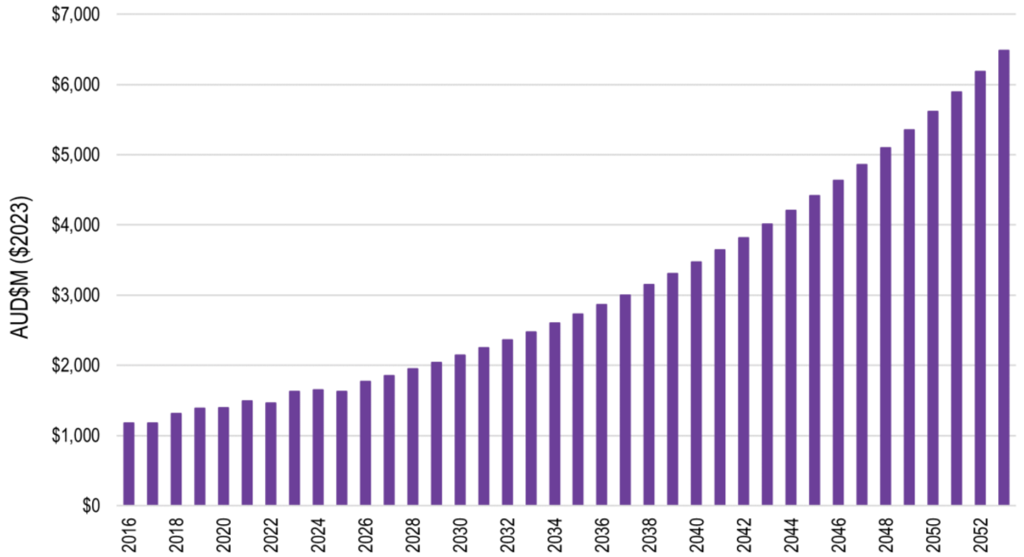

*Source: Australian Strategic Policy Institute 2023, Cost of Defence Public Database.*

Similarly to fuel savings, to model the potential sustainment cost savings generated by adoption of AMAC's composite propeller technology, we estimated an indicative annual spend on sustainment by the Navy from 2027 to 2053 using information from the Cost of Defence Public Database and the following assumptions:

— Around 50% of the Navy sustainment costs relate to vessels where the composite propeller could be potentially adopted (i.e. approximately $1.63 billion in 2023).
— Sustainment expenditure by the Navy from 2027 to 2053 increases at the CAGR in actual expenditure from the last 12 years (2010-11 to 2021-22) – 4.9% per annum.

This results in the sustainment costs of Navy vessels totalling around $6.5 billion in 2053 (in 2023 dollars) – see Figure 7.9.

**Figure 7.9** Estimated sustainment expenditure by Navy vessels, 2016 to 2053 ($m, 2023 dollars)



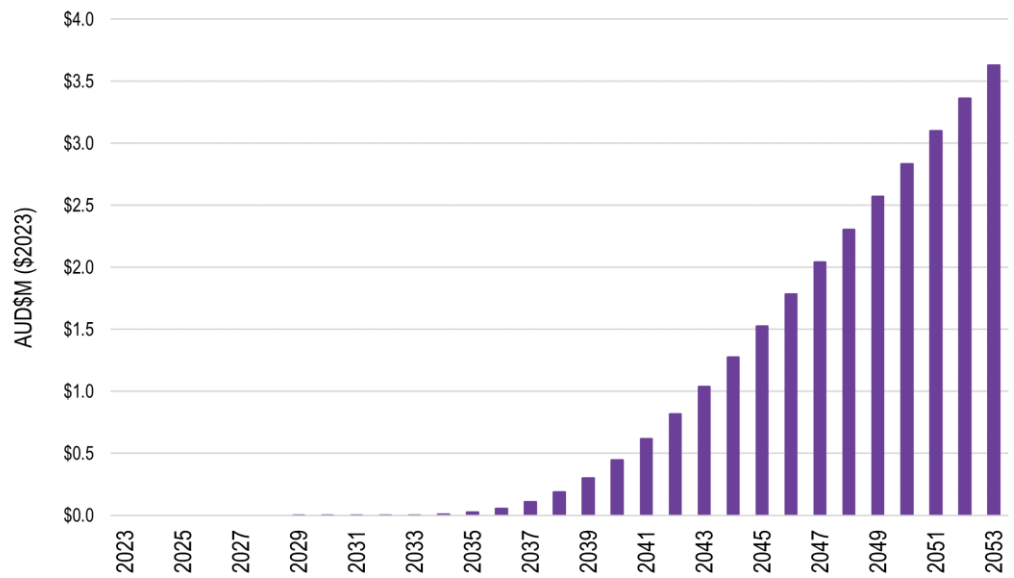

*Source: ACIL Allen*

The potential sustainment cost savings to Defence from adoption of composite propellers in Navy vessels enabled through AMAC research were assessed based on:

— the sustainment cost estimates in Figure 7.9
— the following assumptions:
  – a composite propeller based on AMAC's prototype is available in the market from 2034
  – that 80% of Navy vessels use composite propellers based on AMAC's prototype by the end of the projection period (2053, 20 years from the year that the technology is assumed to go to market – see Figure 7.6)
  – that composite propellers result in a reduction in sustainment costs of 0.2%
  – that, as discussed in Section 7.1.6, 35% of the benefits generated by the composite propeller were enabled/can be attributed to AMAC's research.

The potential sustainment cost savings for the Navy as a result of the AMAC-DSTG research collaboration over the period 2023 to 2053 are shown in Figure 7.10. The present value in 2023 of these benefits using a 7% real discount rate is $5.25 million (in 2023 dollars).

**Figure 7.10** Potential sustainment cost savings for the Navy as a result of adoption of composite propeller derived from AMAC's research, 2023 to 2053 ($m, 2023 dollars)

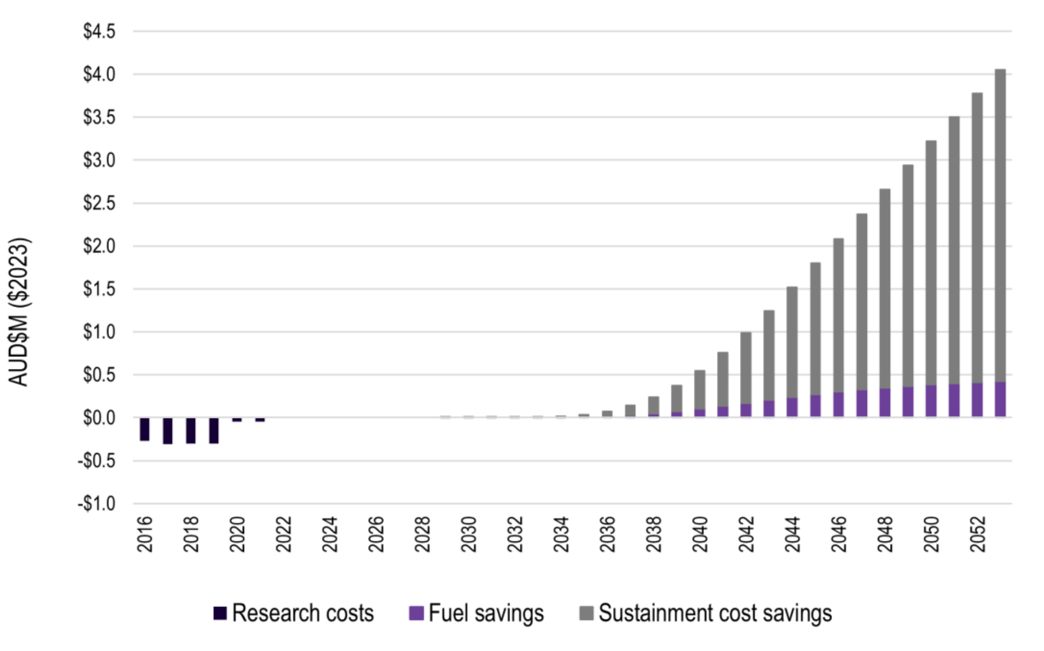



*Source: ACIL Allen*

### 7.2.3 Net impacts

The costs and benefits to Australia from the AMAC-DSTG research collaboration are shown in Figure 7.11.

**Figure 7.11** Costs and benefits to Australia from AMAC-DSTG research collaboration, 2016 to 2053 ($m, 2023 dollars)




*Source: ACIL Allen*

It is estimated that, under the assumptions outlined above, the AMAC-DSTG collaboration could potentially generate (in present value terms in 2023 at 2023 constant prices) approximately $6.1 million in cost savings to the Navy.

In NPV terms, the net benefit of the project in 2023 using a 7% real discount rate, could be $4.3 million (in 2023 dollars).

The BCR of the project is estimated to be 3.40, meaning that for every dollar in research grants invested by AMAC into the composite propeller research, AMAC may enable $3.40 in benefits.

### Sensitivity Analysis

Given the uncertainty associated with many of the assumptions used in the CBA, sensitivity analysis was conducted to assess the sensitivity of the results to substantial changes in the following assumptions:

- discount rate
- assumed adoption of composite propellers by the Navy
- assumed fuel efficiency generated by the adoption of composite propellers
- assumed sustainment cost savings generated by the adoption of composite propellers.

The results of the sensitivity analysis are presented in Table 7.3. As shown in the table, the BCR:

- Increases with:
  - a reduction in the discount rate due to the time value of money (i.e. a dollar today is worth more than a dollar tomorrow)
  - an increase in:
    - the assumed adoption of composite propellers by the Navy
    - assumed fuel efficiency generated by the adoption of composite propellers
    - assumed sustainment cost savings generated by the adoption of composite propellers

- Decreases with:
  - an increase in the discount rate
  - a decrease in:
    - the assumed adoption of composite propellers by the Navy
    - assumed fuel efficiency generated by the adoption of composite propellers
    - assumed sustainment cost savings generated by the adoption of composite propellers.

In all cases, substantial changes to the assumptions were not sufficient to result in a BCR of less than one (or a negative NPV).

**Table 7.3** Sensitivity analysis – impact of sensitivity tests on the economy-wide impacts

| | NPV ($M) | BCR |
|---|---|---|
| **Central case** | **$4.3** | **3.4** |
| **Discount rate** | | |
| Decrease from 7% to 3% | $14.0 | 10.5 |
| Increase from 7% to 10% | $1.1 | 1.5 |
| **Changes in adoption of composite propellers by Navy 2053** | | |
| Reduced adoption by 50% (from 80% to 40%) | $1.4 | 1.8 |
| Increased adoption to 100% | $5.7 | 4.2 |
| **Changes in fuel efficiency generated by composite propellers** | | |
| Reduced efficiency by 50% (from 1.5% to 0.75%) | $3.9 | 3.1 |
| Increased efficiency to 2% (maximum in range suggested by AMAC researchers) | $4.6 | 3.5 |
| **Changes in sustainment cost savings generated by composite propellers** | | |
| Reduced cost savings by 50% (from 0.2% to 0.1%) | $1.7 | 1.9 |
| Increased cost savings by 50% (from 0.2% to 0.4%) | $9.5 | 6.3 |

*Source: ACIL Allen.*

# Case study: Bridge Monitoring 8

Structural health monitoring (SHM) refers to the process of designing and implementing a condition monitoring and characterisation strategy for engineering structures.[40] SHM responds to the need to increase the safety and optimise the maintenance costs of structures through the implementation of objective, science-based inspection practices. SHM is a relatively new field which has been enabled by the emergence of improved construction materials and methods, new developments in measurement, sensing, processing, and monitoring, alongside other recent technological developments in various branches of science and engineering.[41]

**Steelwork of a bridge in NSW**

*Source: iStock*

SHM uses long term monitoring systems to keep civil infrastructure under constant surveillance, ensuring structural integrity. Therefore, it has a range of applications including for buildings, dams, tunnels, aerospace, and bridges. SHM is commonly used for bridges due to their critical role in transportation, and can detect issues like corrosion, fatigue, and foundation settling. SHM has the potential to transform the bridge engineering industry by providing stakeholders with additional information to inform decisions about the design, operation, and management of bridges throughout their life.[42]

AMAC was approached by Transport for New South Wales (TfNSW) to undertake a collaborative research project to monitor the health of steel riveted bridges in NSW.

Fibre optic sensors are viewed as the technology with highest potential for continuous real-time monitoring of large structures due to their advantages such as small size and weight, resistance to electromagnetic interference, large data transmission bandwidth and resistance to corrosion.[43] TfNSW noted that they had been aware of publications by AMAC which successfully demonstrated the use of distributed fibre optic sensors to detect delamination between layers of composites. The concept was attractive to TfNSW due to its potential use in monitoring locations of stress in bridges, and to monitor complex bridges components for actual vehicular loads.

A project was thus set up to verify if long term structural monitoring for varying loads was practical with the use of both discrete and continuous fibre optic gauges. Riveted bridge members and

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[40] Alla, A., Asadi, S.S. (2020). Integrated methodology of structural health monitoring for civil structures, Materials Today: Proceedings, Volume 27, Part 2, Pages 1066-1072, https://doi.org/10.1016/j.matpr.2020.01.435.

[41] UNSW, (2024), Structural Health Monitoring Fundamentals and Practices, available online at: https://www.handbook.unsw.edu.au/undergraduate/courses/2024/CVEN9840?year=2024

[42] P.J. Vardanega, G.T. Webb, P.R.A. Fidler, F. Huseynov, K.K.G.K.D. Kariyawasam, C.R. Middleton. (2022). Innovative Bridge Design Handbook (Second Edition),Butterworth-Heinemann, Pages 893-932, https://doi.org/10.1016/B978-0-12-823550-8.00023-8.

[43] SoMAC. (2021). The SoMAC CRC prospectus. https://advanced-composites.co/wp-content/uploads/2021/02/The-SoMAC-CRC-Prospectus-20210208c-Appendix.pdf

connections was the focus of the study. An additional aim was to detect the measure of failure in riveted connections in laboratory tests under differing levels of fatigue and static loads.

## 8.1 Impact Pathway

Figure 8.1 below provides a high-level overview of the impact pathway of the AMAC and TfNSW collaboration.

**Figure 8.1** Impact pathway

| INPUTS | ACTIVITIES | OUTPUTS | OUTCOMES | IMPACTS |
|---|---|---|---|---|
| – Total funding of $150,000 from TfNSW ($50,000 per year for 3 years)<br>– PhD grant of $31,212 per annum for 3.5 years funded through original ARC grant | – Testing the feasibility of monitoring the structural health of steel riveted bridges in NSW with fibre optic sensors. This included:<br>– lab level testing of the fibre optic sensors durability<br>– lab level testing of the sensor's damage detection potential<br>– conducting field testing on one of TfNSW's structures | – Data from fibre optic sensor testing to inform future TfNSW decision making on asset SHM<br>– Development of 4 journal articles (one already published and 3 in progress)<br>– Increased skills and knowledge of practical applications of fibre optic sensors for AMAC researcher | – Future outcomes could include the development of a structural health monitoring platform with real-time data on NSW steel rivetted bridges including:<br>– strain data<br>– displacement data<br>– cyclic loading<br>– life cycle data<br>– diagrams showing bending/ movement of the bridge's structural components<br>– temperature data | Potential future impacts (if SHM platform is introduced) include:<br>**Economic**<br>– Postponed structural intervention<br>– Extended service life of bridges<br>– Prevention of fatigue cracks<br>**Environmental**<br>– Reduced waste and resource cost from extending the service life of bridges<br>**Social**<br>– Avoided social costs from avoided bridge failure (e.g. negative impacts on community from injury and damage) |

*Source: ACIL Allen, AMAC*

### 8.1.1 Project inputs

Project inputs refer to the resources used/invested in a project to implement it and deliver the intended results. In this case study, this refers to resources invested by AMAC in the SHM research project. The project was officially signed in 2018 and commenced in 2019. It is assumed that funding commenced with the start of the project in 2019.

AMAC received $50,000 per annum over 3 years from TfNSW for this project. A PhD grant of $31,212 per annum for 3.5 years was funded through the original ARC grant funding (rather than through the industry partner funding, see Table 8.1).

**Table 8.1** Cash support for the SHM project

| Funding Organisation | Grant Amount | Duration |
|---|---|---|
| TfNSW | $150,000 | 3 years (2019-2021) |
| ARC | $109,242 | 3.5 years (2019-2022) |
| **Total** | **$259,242** | |

*Source: AMAC*

### 8.1.2 Project Activities

The key activity for this project was to test the feasibility of using fibre optic sensors for the SHM of steel riveted bridges in NSW. This research activity was carried out through the following 3 stages which occurred between 2019 and 2023:

1. The initial research was conducted at the lab level, on a single-riveted structure. During this stage, AMAC and TfNSW investigated the fibre optic sensor's durability. This included running tests which simulated vehicles continually crossing the structures that the sensors would be placed on. Tests to understand the suitable placement of fibre optic sensors were also conducted. Appropriate adhesives for bonding the sensors to the target structures were also investigated. The test results showed that once placed, the fibre optic sensors would have a useful life of 20 years.
2. The second stage was also at the lab level, this time of multi-riveted structures. The key focus of the second stage involved testing how the sensors responded to individual bridge components. The team conducted cyclic testing and static testing over 3 load levels to examine the data output of the sensors. The sensors were tested to see if they could accurately provide data when presented with a component in damaged and undamaged condition.
3. The third stage involved field testing over the course of a month to examine the performance of the sensors in practical conditions. This involved 1 week of site surveying, 1 week of installing the fibre optic sensors, and 2 weeks of capturing data. This included testing whether the sensors could accurately pick up signals of vehicles travelling at 60-70km/hr speeds.

### 8.1.3 Project outputs

The outputs of the structural health monitoring project include:

- data from fibre optic sensor testing
- future journal articles
- increased skills and knowledge.

**Data from fibre optic sensor testing**

The AMAC research collaboration resulted in a significant amount of data collection, which demonstrates how and where fibre optic sensors can be installed, how long they are likely to last and what information they can collect. TfNSW can use these findings to make future decisions around its infrastructure and the structural health monitoring of these assets.

**Journal articles (to be published)**

The AMAC and TfNSW collaboration has resulted in the development of 4 journal articles. As of June 2024, one journal article has been published and 3 are currently in the publication process.

### Increased skills and knowledge

An AMAC researcher involved in the project noted that it resulted in a greater understanding of the practical applications and challenges of fibre optic sensors and structural health monitoring. The researcher's expertise was on the sensors themselves, the technology underpinning them and how to conduct the testing. However, to tailor the technology to fit specific assets, and to understand the structural behaviours of sections of the bridges required new skills and knowledge which were obtained through the study. The project has resulted in the successful completion of one PhD.

## 8.1.4 Project outcomes

As of the time of writing, there have been no public decisions made in relation to the SHM of riveted steel bridge assets in NSW. However, significant outcomes can be expected if the technology was to be implemented in the future.

A complete installation of fibre optic sensors to a bridge asset would provide the data needed to establish an SHM platform (a user-friendly program interface that interprets data for SHM). This platform would provide TfNSW with continuous monitoring and real time information including:

— strain data
— displacement data
— cyclic loading
— life cycle data
— diagrams which show bending/movement of the asset
— temperature data.

The strain data is expected to be highly beneficial for TfNSW, as it will provide data on how particular sections of a bridge are performing, and the strain levels on the structure overall.

The data could also be used in riveted bridges to monitor performance under live traffic, provide a scientific basis that would complement desktop studies before intervention, and identify fatigue risks and/or damage under repetitive loads. Using the sensors, AMAC has developed suitable crack/damage localisation algorithms to accurately determine structural damage which could be implemented in future.

AMAC has stated that the data from the sensors could be integrated with a machine learning platform to provide a localised structural health score that will assist the TfNSW engineers to evaluate the structural health of a bridge.[44]

## 8.1.5 Project impacts

### Economic

As discussed above, a potential future outcome of the research would be the development of a structural health monitoring platform to monitor steel rivet bridges in NSW. This platform will allow TfNSW to understand the true performance of a bridge in real-time, which may result in the following potential future impacts.

— *Postponed structural intervention*: having access to data on the true status of a bridge will reduce the need for visual maintenance and result in structural intervention of the bridge being postponed until data indicates that it is required. TfNSW also noted that SHM would eliminate intervention based merely on desktop analyses of potential maximum loads from vehicles, and will provide a more scientific rationale for intervention based on actual traffic and fatigue damage from repetitive cycles SHM leads to an overall shift in the approach to bridge

[44] SoMAC. (2021). The SoMAC CRC prospectus. https://advanced-composites.co/wp-content/uploads/2021/02/The-SoMAC-CRC-Prospectus-20210208c-Appendix.pdf

structural intervention, from preventive or corrective intervention to condition-based intervention, meaning that intervention can occur at the most effective time.[45]

— *Extended service life of bridges:* data on the true status of a bridge may result in more informed decisions for the replacement of bridges. Results from a 2018 report showed that the replacement of the bridge investigated in the study could be postponed by up to 37 years through the use of SHM, because the condition of the bridge was determined to be better than what was previously assumed.[46]

— *Prevention of fatigue cracks:* SHM of aged bridges may prevent fatigue cracks. Prevention of fatigue cracks could protect bridge assets from accelerated failures, and in extreme situations bridge section/member failure. The likelihood of a failure resulting in a bridge collapse is extremely small. Studies show that the likelihood of a bridge collapsing is 1/4700, and of these only 4% involve a loss of life.[47] However, regardless of this small probability, the consequences of a bridge collapse can be catastrophic and result in vehicle damage, detour costs, injuries and death.[48] By knowing the true performance of a bridge in real-time, fatigue cracks and in extreme scenarios bridge failure can be effectively prevented using SHM.

Another potential impact of SHM is the avoidance of unplanned maintenance on steel riveted bridges. Due to the uncertainty of the frequency and scale of unplanned maintenance, it is difficult to quantify the economic costs of this type of maintenance. In 2018, a study estimated that a major disruption on the Sydney Harbour Bridge on a weekday morning could cost up to $10 million (about $11.9 million in 2023 dollars) due to the impact of people being prevented from, or delayed in, reaching work. This provides an indication of the scale of economic harm that unplanned maintenance could result in if the bridge is part of a major transportation route.[49]

**Environmental**

Extending the life of steel riveted bridges through better and more targeted maintenance is also expected to result in potential environmental benefits. Demolition of bridges can result in the generation of a significant amount of waste and debris, and bridge reconstruction is a resource intensive exercise. Extending the useful life of steel rivetted bridges delays the process of demolition and reconstruction, which over multiple life cycles of a bridge will reduce overall environmental impact.

**Social**

As discussed above, impacts in the unlikely event of a bridge failure or collapse include vehicle damage, detour costs, injuries and death. These impacts do not only have direct economic costs but significant indirect impacts on the welfare of the wider community. For example, the collapse of the Ponte Morandi motorway bridge in Italy in August of 2018 due to structural failure killed

[45]Phares, B., Lu, P. (2018). Integration Of Structural Health Monitoring Into Multilayer Statewide Bridge Maintenance And Management Practices – SHM Facilitated Condition-Based Maintenance Prioritization System. https://cdn-wordpress.webspec.cloud/intrans.iastate.edu/uploads/2019/02/SHM_multilayer_statewide_bridge_mtc_and_mgmt_w_cvr.pdf

[46] Ibid.

[47] Ibid.

[48] Ibid.

[49]Wade, M., Clun, R. (2018). Traffic chaos from Sydney Harbour Bridge drama cost city up to $10 million. https://www.smh.com.au/national/nsw/traffic-chaos-from-sydney-harbour-bridge-drama-cost-city-up-to-10-million-20180404-p4z7rb.html

43 people and left 600 homeless.[50] SHM can effectively prevent bridge failure and/or collapse through real-time insights of bridge performance, resulting in potential social benefits of avoiding these tragic incidents.

### 8.1.6 Clarifying the impacts

A CBA was not conducted for this case study given the sensitive nature of TfNSW's work.

[50]Mattioli, G. (2019). What caused the Genoa bridge collapse – and the end of an Italian national myth? https://www.theguardian.com/cities/2019/feb/26/what-caused-the-genoa-morandi-bridge-collapse-and-the-end-of-an-italian-national-myth

# AMAC PhD and researcher survey 9

As discussed in Chapter 4, a short PhD and researcher survey was distributed to relevant stakeholders identified by AMAC to capture the Centre's contribution to building research capacity and capability in composite manufacturing and understand how AMAC has impacted these individuals' career journeys.

Over the funding period (2017 to 2022), a total of 57 participants engaged in the AMAC training, comprised of:

— 23 PhDs
— 24 research associates across various projects
— 10 visiting research staff.

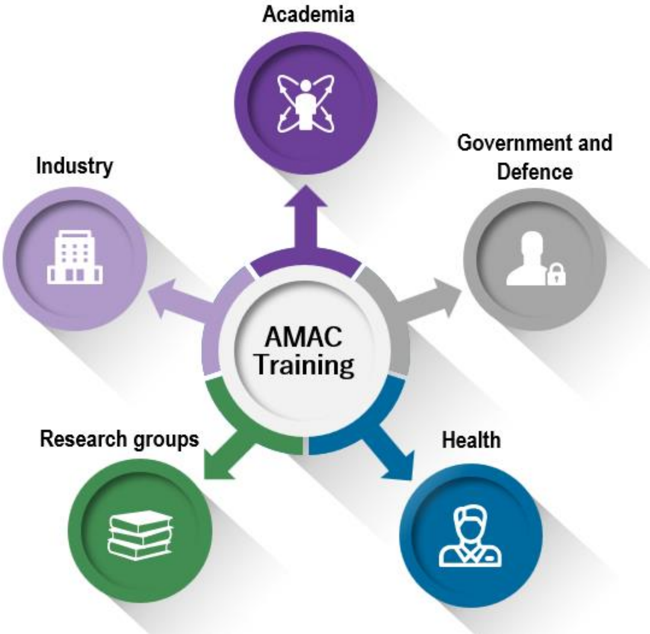
The survey was distributed to all these participants, and we received a total of 30 total complete responses. Those who responded to the survey were largely comprised of members of academia from the UNSW, based in Australia, and with a focus in manufacturing, and education and training. A summary of the survey results is presented in Figure 9.1.

**Figure 9.1** Summary of AMAC training survey


*Source: ACIL Allen*

The results of the survey also demonstrated that the AMAC training opened multiple pathways for PhD students and researchers. Figure 9.2 illustrates some of the pathways identified from the survey responses.

**Figure 9.2** AMAC training pathways

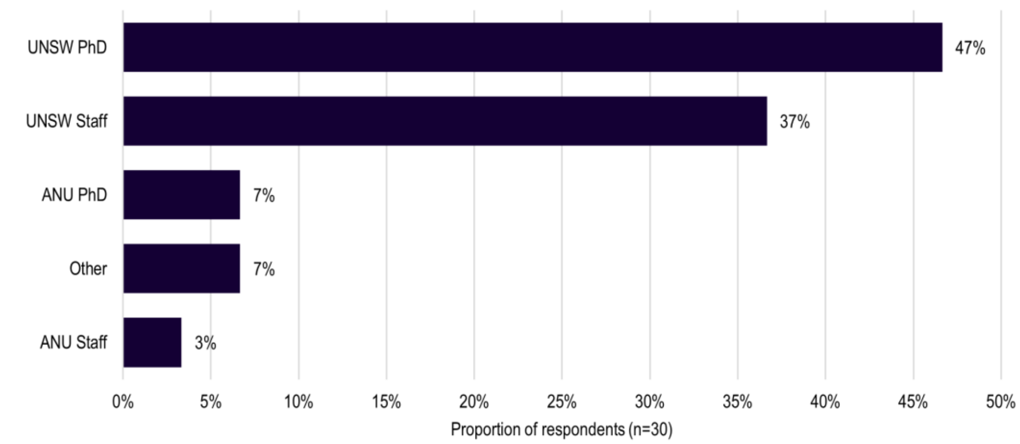



*Source: ACIL Allen*

## 9.1 Surveyed participants' characteristics

Of those surveyed, the majority of participants were affiliated with UNSW (83%) while receiving AMAC training, as both PhD candidates and as staff. A smaller group were from the ANU (10%) (Figure 9.3).

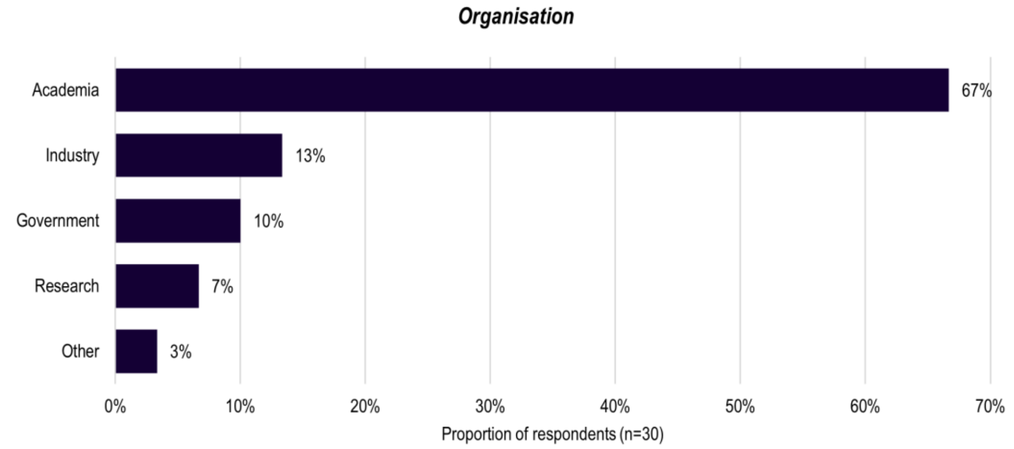
**Figure 9.3** AMAC Survey – survey respondent's affiliation with AMAC




*Source: Survey of AMAC training recipients, 2024. Administration and analysis by ACIL Allen, 2024.*
*Survey Question: [What was] your past affiliation with AMAC?*

Analysis of the respondent's current organisations showed that most have continued into positions in academia (67%, Figure 9.4), largely based in Australia at UNSW, but also at international institutions including the Southern University of Science and Technology (China), University of Strathclyde (Scotland), Cardiff Metropolitan University (Wales) and Delft University of Technology (Netherlands). Survey respondents also reported having transitioned to industry (13%), to organisations including BYD Auto and Omni Tanker, as well as to government (10%), including to defence and health agencies. Some respondents have also transitioned to research organisations (7%) such as CSIRO and Cooperative Research Australia.

**Figure 9.4** AMAC Survey – sectoral analysis of survey participant's current organisations



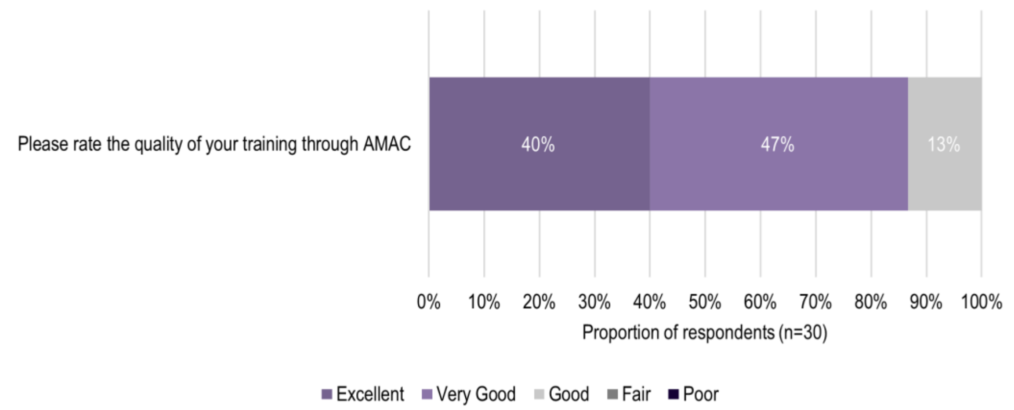

*Source: Survey of AMAC training recipients, 2024. Administration and analysis by ACIL Allen, 2024.*
*Survey Question: [Please provide the name of] your current organisation*

## 9.2 Quality of AMAC training

Survey participants considered AMAC's training to be of high quality and relevance to their current work, although only some participants considered the training to be unique.

Most surveyed participants (87%) considered the training to be either very good or excellent (Figure 9.5), with the remainder indicating that it was good. No respondent considered the training to be fair or poor, reflecting a high level of satisfaction with the quality of training delivered by AMAC.

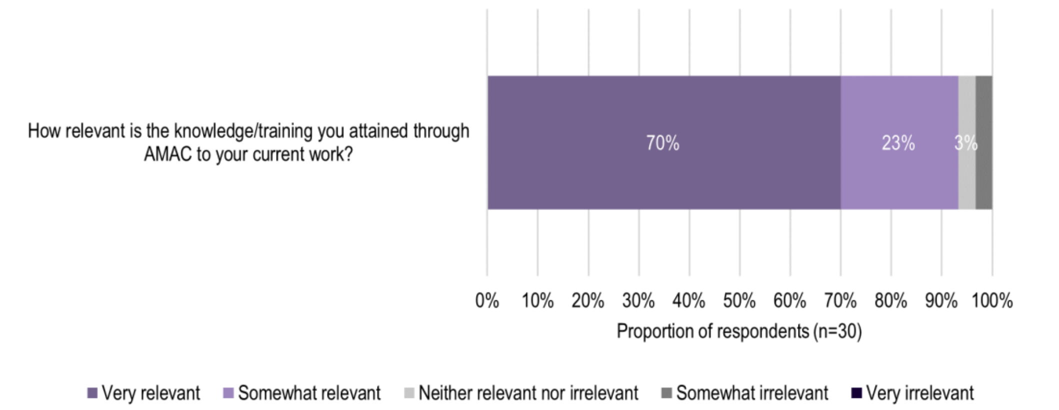
**Figure 9.5** AMAC Survey – respondents' views on quality of AMAC training




*Source: Survey of AMAC training recipients, 2024. Administration and analysis by ACIL Allen, 2024.*

Overall, training recipients considered AMAC's training to be relevant to their current work. Indeed, most surveyed participants (70%) considered the training to be very relevant (Figure 9.6), with only one individual finding it to be somewhat irrelevant.

**Figure 9.6** AMAC Survey – respondent's views on relevance of AMAC training




*Source: Survey of AMAC training recipients, 2024. Administration and analysis by ACIL Allen, 2024.*

Participants indicated a range of areas that they were supported in through the AMAC training, spanning both technical and soft skills. Technical knowledge skills developed for trainees included advanced skills such as numerical modelling, coding language development, and advanced automated manufacturing. These concepts and techniques are considered relevant and appropriate for the specific lines of research being pursued through academia and considered to be relevant to further work in industry.

*"The support provided by AMAC has allowed me to significantly develop my skills in composites design and manufacturing which I am very likely to capitalise on after I graduate"*
*(Survey respondent)*

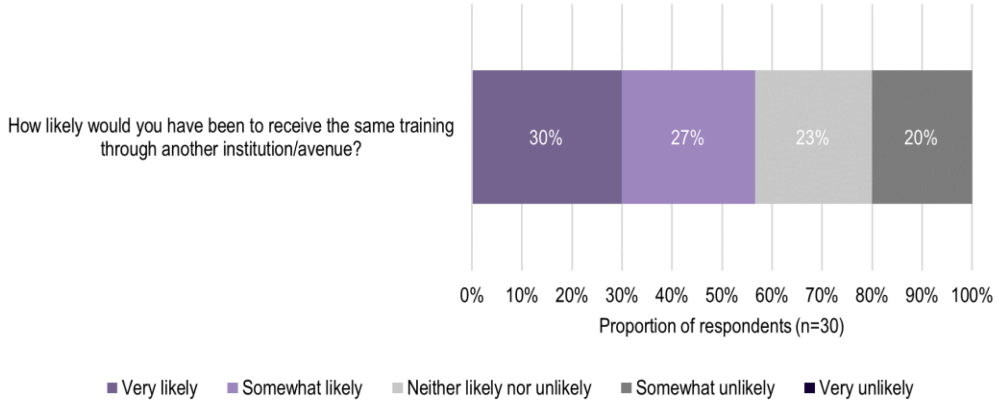
Participants also highly valued the soft skills components of the training, relevant to their research and further roles in academia and industry. Training recipients highlighted the collaboration, project management and critical thinking skills that are transferable across sectors and research areas.

> *"The training at AMAC doesn't only comprise of the technical knowledge we received there, instead, we developed several soft skills, learned how to work in a collaborative environment and most importantly, it was the first step towards becoming an independent researcher in future."*

*(Survey respondent)*

Fewer than half of surveyed training participants indicated that the training was unique, considering it somewhat or very unlikely that they would be able to receive this training with another institution or via another pathway (43%, Figure 9.7). The remaining respondents indicated that it is likely they could find and receive the same training elsewhere.

**Figure 9.7** AMAC Survey – respondent's views on uniqueness of AMAC training



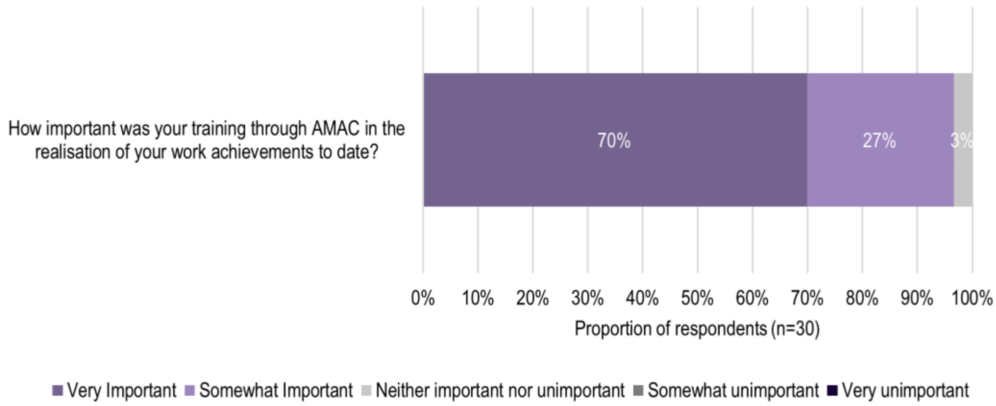

*Source: Survey of AMAC training recipients, 2024. Administration and analysis by ACIL Allen, 2024.*

## 9.3 Impact of AMAC training

The AMAC training has been important to participants' professional achievement, and their high value of the program is reflected in their support for further training.

Almost all surveyed training participants indicated that the training was important to them in realising their work achievement to date (97%, Figure 9.8). No respondent indicated that it was in any way unimportant.

**Figure 9.8** AMAC Survey – respondent's views on importance of AMAC training




*Source: Survey of AMAC training recipients, 2024. Administration and analysis by ACIL Allen, 2024.*

Beyond direct technical knowledge and skills developed in the training, participants considered the longer-term impacts to be considerable with regards to research completion and graduation from AMAC. Participants were able to network effectively with peers and achieved greater awareness and recognition for their work.

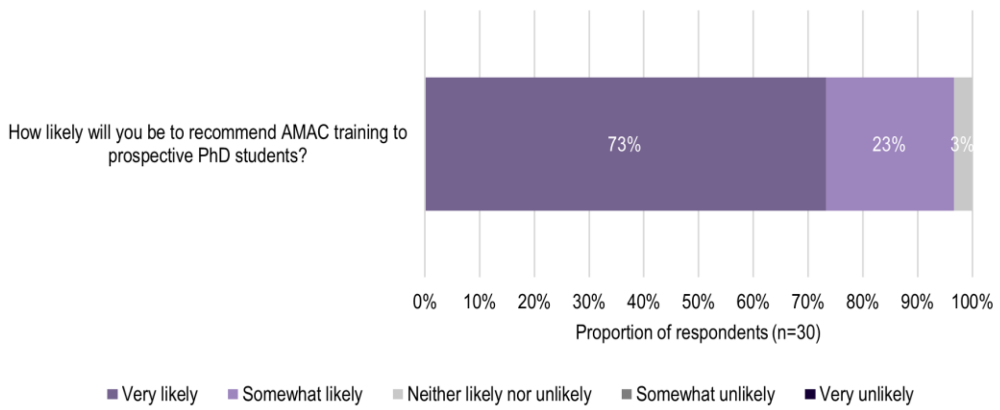
> *"I have developed a composite propeller blade manufactured using Automated Fibre Placement robot, and the product was able to gain international recognition and begged the JEC Asia 2019 Innovation award in the marine category."*
>
> *(Survey respondent)*

In some cases, this recognition was able to translate into commercial success and impact and influence in a number of publications. This dissemination and proliferation of work reflects the depth and penetration of impact of the AMAC training.

> *"The training I received in Dental Materials has led to the successful commercialization of two dental composites, with another piece of equipment nearing commercialization. This project stands out within the research field as one of the few to bring tangible products to market fruition."*
>
> *"As a direct outcome of my research activities within AMAC, I published several papers in high impact journals and presented at prestigious international conferences. In addition, I have given several workshops to industry partners, both Australian and international."*
>
> *(Survey respondents)*

Almost all surveyed participants indicated that they would recommend AMAC training to prospective PhD students (97%, Figure 9.9).

**Figure 9.9** AMAC Survey – respondent's views on whether they would recommend the AMAC training




*Note: figures may not add to 100% due to rounding.*

*Source: Survey of AMAC training recipients, 2024. Administration and analysis by ACIL Allen, 2024.*

# Conclusion 10

Through this engagement, ACIL Allen assessed the impacts of the Centre over its funding period (2017-2022) to demonstrate the significant benefits that are possible through collaborative research and training. ACIL Allen investigated the potential and delivered impact of the following 4 research projects through case studies:

— dental composites research undertaken with SDI Limited
— composite tanker research undertaken with Omni Tanker
— composite propeller blade research undertaken with Defence Science and Technology Group
— bridge structural health monitoring research undertaken with NSW Department of Transport.

Using an impact pathway approach, we evaluated the impacts of these projects and identified a range of quantifiable and unquantifiable benefits. These included economic impacts, research capability and capacity building, environmental impacts, contribution to knowledge, leveraging of additional investment, and the contribution to the establishment of the ACM CRC. We also conducted a survey of former AMAC PhD students and Post Doctoral staff and received overwhelmingly positive feedback on the quality of the training, the relevance of the training to current work, and the importance of the training to realising work achievements.

ACIL Allen conducted an indicative CBA for 3 of the 4 research projects above to estimate the potential and delivered economic benefits that have or could be attributed to AMAC's research. All impacts have been adjusted for attribution to AMAC (see Table 10.1). For all research projects analysed, the NPV is above zero and the BCR is above one. This means that the benefit of all projects has outweighed or are likely to outweigh the costs, which will deliver a net benefit to Australia. To put the scale of the benefits in perspective, the benefits enabled by AMAC through the dental composite research alone more than doubles the total costs of all other research undertaken at AMAC (i.e. it is enough to cover both the ARC grant and the funding leveraged from other sources).

**Table 10.1** CBA summaries of the 4 research projects assessed in this study (central 7% discount rate, $2023)

| Project title | Research status | PV Costs ($m) | PV Benefits ($m) | NPV ($m) | BCR |
|---|---|---|---|---|---|
| **Dental composites** | Commercialised | $3.0 | $23.9 | **$20.9** | **7.9** |
| **Composite tanker** | Commercialised | $0.3 | $3.0 | **$2.7** | **9.0** |
| **Composite propeller blade** | Not commercialised – illustrative CBA | $1.5 | $6.1 | **$4.3** | **3.4** |

*Note: the dental composites and composite tanker CBAs are based on research that has been commercialised, while the research conducted for the composite propeller blade project is yet to be commercialised. The impacts of the composite propeller blade project is for illustrative purposes to demonstrate the potential impacts if the research was implemented.*

*Source: ACIL Allen*

The impacts identified and the results of the training survey and project CBAs demonstrate the significant benefits delivered through AMAC's collaborative research and training. The strength of the relationships that AMAC has created are a testament to the Centre's dedication to advancing composite research in Australia and developing the next generation of innovators in this industry. The impacts of AMAC's research will extend beyond the Centre's funding period, which is already evident from its involvement in the commercialisation of research, the significant number of publications and PhDs developed and trained, and the emergence of the ACM CRC. The strong relationships built through the Centre will likely enable the realisation of future impacts for UNSW, the ACM CRC and AMAC's partners.

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# Appendices

# Example projects by research area

A

## A.1 Materials enhancement project examples

- *Graphene-enhanced prepreg tapes for thermal and electrical conductivity:* this project explores the spray deposition of exfoliated graphene in liquid suspensions for the nano-enhancement of electrical properties in carbon-fibre reinforced polyether ether ketone (CF-PEEK) composites. The addition of 1.3 wt% (percentage by weight) graphene into the interlayers of CF-PEEK composites resulted in bulk electrical conductivity enhancement both in-plane (1100% improvement) and through-thickness (300% improvement), which could open simple pathways for the in-situ manufacturing of carbon-fibre reinforced polymer nanocomposites.
- *Durable nano-scale surface treatments to improve wear and environmental resistance:* Exploring superhydrophobic coatings to protect 3D-printed carbon-fibre/polyamide (CF/PA) composites against moisture-induced degradation. The presence of the superhydrophobic coating eliminated the liquid water present in the surface features of the polyamide matrix and reduced the moisture-induced swelling of the polyamide matrix by about 53% after 168 hours underwater.

## A.2 Process-property optimisation project examples

- *Smart Composites-Integration of Sensing and Actuating Elements:* This work focused on vibration damping using active elements such as macro fibre composite (MFC) piezoelectric patches as sensors and actuators. This approach allowed for the quick and efficient determination of complex beam configuration responses, enabling rapid analysis and design refinement, to understand the optimal locations within structures for these patches.
- *Thermoplastic AFP optimisation for metallic bonding:* This required an in-depth understanding of the laser absorption process and the thermal and pressure properties of the materials examined. It was found that the material selection had a strong influence on both the success and quality of the metallic bonding reinforcement process. The researchers investigated and identified textures suitable for laser Automated Tape Placement (ATP) and developed and successfully demonstrated approaches to applying carbon-fibre/thermoplastic composites directly to laser-textured steel substrates using laser-ATP.
- *Post-forming of thermoplastic AFP composite tubes:* This project investigated the post-forming of carbon-fibre/thermoplastic composite tubes. These tubes were manufactured by laser-assisted automated tape placement on a winding axis and then post-formed by locally heating the tube to near melting point. The relationship between the winding angle and the formability was investigated through this process. A model was developed to predict how the manufacturing process affected the material's properties.

## A.3 Simulation and performance prediction project examples

- *Bend-twist coupling behaviour through fibre steering:* By tweaking the layup[51] orientations during the manufacturing process, bend-twist coupling can be induced in composite marine propellers which allows for passive pitch changes. Consequently, this improves hydrodynamic efficiency over a larger operational range. This work presents the first experimental validation of a curvilinear tow design in a hydrofoil by using automated fibre placement. The manufacturing complications arising from tow steering in a three-dimensional convex mould were also investigated.
- *Implementing cohesive elements in scaled boundary finite element for predicting delamination:* Scaled boundary finite element method (SBFEM) provides a benefit over the traditional finite element method by discretising the sub-domain boundaries only. The stresses within a sub-domain are solved analytically. Such simulation techniques are highly efficient in resolving stresses around a sharp notch where high fidelity is required while low fidelity is needed for far-field stresses.
- *Design and development of composite conveyor support structures for mining environment:* Direct and indirect costs of back injuries to miners are estimated to cost the Australian mining industry $918,000 per megaton of coal sold. Many such injuries can be attributed to the need for underground miners to physically transport heavy machinery in confined spaces. A potential solution is to develop lightweight components from carbon fibre composites. This project demonstrated the use of composite materials in underground conveyor support structures. Mechanical, fire and anti-static testing was performed to select the appropriate fibre and polymer resin to meet the mining standards for underground mines. The design and optimisation of the support structure have been completed and a full-scale test implementation is in process.

## A.4 Design, integration and optimisation

- *Manufacture of composite wheel for automotive industry:* Due to the complex geometry of wheels used in the automotive industry, AMAC undertook research to construct a composite wheel out of 3 parts: the inner and outer rim, and the disc. The AFP manufacturing technique was combined with a hand layup technique to manufacture the composite wheel prototype. The wheel was tested, and the results were submitted to the Journal of Advanced Manufacturing Technology.
- *Automated manufacture of adaptive composite propellers*: Marine propellers are susceptible to grounding, and collision with debris and marine animals. The work focused on understanding the low-velocity impact behaviour of laminated carbon fibre composites in marine environments focusing on the experimental and numerical prediction of thick-sectioned composites, underwater aging of impact-damaged laminated composites and damage prediction of underwater low-velocity impact on composite laminates.
- *Manufacture of Type V hydrogen storage tanks:* This project aimed to assess the capability of AFP manufacturing technology for manufacturing thermoset-based composite tanks for hydrogen storage. A Type V composite pressure vessel was designed, manufactured and tested. A novel collapsible mandrel tool suitable for AFP based manufacturing was developed for this project.

[51] A layup process is a moulding process for composite materials, in which the final product is obtained by overlapping a specific number of different layers, usually made of continuous polymeric or ceramic fibres and a thermoset polymeric liquid matrix.

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