Titanium Technologies Workshop

DMTC
DEFENCE MATERIALS TECHNOLOGY CENTRE

Australian Government
Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education

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Executive Summary

The Defence Materials Technology Centre (DMTC) with support from the Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education (DIICCSRTE), conducted a series of workshops to discuss research, opportunities, challenges and barriers in the Australia titanium sector. The objective of the workshops was to identify what the future direction of the titanium industry is in Australia.

This study has presented a sector which, although highly capable in key areas, continues to face considerable challenges in terms of matching technology supply and demand driven by global market trends. These factors frame the discussion on future investment in titanium technologies for government, industry and research sector organisations, and provide a key starting point for future discussions with the Australian industry sector.

Australia has invested in titanium research across the full spectrum of technologies and processes ranging from extractive metallurgy through alloy development and component fabrication and production. This report has compared the state of maturity of Australian research activities with that of global best practice. This found that Australian technology development activities in titanium cover a broad range of the titanium life-cycle and in most cases represent a wide degree of technical maturities. Australian research and technical activities are broadly consistent with global best practice in fabrication technologies (such as machining, welding and casting), and close to best practice in heat treatment technologies, but remain some way behind best practice in other areas.

Industry participants identified many opportunities for growth in the titanium sector that, when coupled with the technical expertise present in Australian research organisations and the potential for international investment could drive innovation and growth in the titanium sector:

- There has been considerable progress in titanium technology which will increase the range of usage in a broad range of industries where there is a strong domestic and international demand.
- Aerospace and Defence sectors are experiencing significant increases in the percentage of airframe weight by titanium providing opportunities for local companies to connect with international supply chains.
- Due to its high strength to weight ratio and resistance to corrosion, opportunities exist for utilising titanium in medical devices, implants, food, consumer, marine and energy / geothermal applications.
- Investment in automation, manufacturing technology and productivity is important for Australian small and medium enterprises (SMEs) to remain competitive with lower cost countries, particularly as they move up the technology chain.
- Improved fabrication techniques and additive manufacturing is opening up new market and investment opportunities in Australia for local and international companies.
- To increase industry pull in titanium technology research, a coordinated approach to informing industry about technology developments and transfer of the technology to industry is required.

A national approach incorporating a coordinated, strategic development pathway for selected titanium technologies, based on informed business case assessments could ensure stronger industry engagement and lead to better development outcomes of greater commercial application. This would require a long term commitment and coordination between various State, Commonwealth, industry and Research sector organisations. Technology roadmapping would be a useful tool in this respect to understand long term industry strategic goals and the short term technology requirements required to meet these goals. This will allow for an informed national strategy to be developed.

Contents

1 Introduction

The DMTC is focused on improving manufacturing / materials capability in the Australian industry sector and facilitated a one-day, research focused workshop to bring together the main Australian researchers in titanium technology to discuss the current stage of titanium research in Australia and to identify possible future opportunities and required strategies to allow a range of opportunities to be realised, both in terms of industry development and research sector support. The DMTC also conducted two one-day industry focused workshops to discuss, with industry, the opportunities, challenges and barriers to the growth of the titanium sector in Australia.

1.1 Previous Reviews of the Australian Titanium Industry

Titanium has been the subject of a number of reviews and studies since the early 2000's (see Section 7 for references). These reports largely focused on extraction and processing technologies and have not looked at the technology maturity in areas such as fabrication and additive manufacturing.

One of the first reports to look at developing a titanium industry in Australia was "*Australia Leading the Light Metals Age*", 2001, commissioned by the Light Metals Action Agenda Strategic Leaders Group. In the context of titanium, the report concentrates on Australia's significant natural resources to provide a platform for future growth, particularly when coupled with CSIRO's TiRO™ technology to produce lower cost raw material and therefore make Australian manufacturers internationally competitive, driving a number of market segments. The ability of Australian businesses to capture these opportunities is discussed at a high level and not in terms of downstream technology or supply chains.

In 2008, the Australian Bureau of Agricultural and Resource Economics (ABARE) looked at "*Research and development in titanium: implications for a titanium metal industry in Australia*". This report looked exclusively at the role of government in supporting CSIRO's TiRO™ R&D project and pilot plant. The report looked at the economic rationale for consideration of government intervention in the technology innovation process, however not downstream technology or industry capability.

In 2011, CSIRO commissioned "*Additive Manufacturing – Technology Roadmap for Australia*" to outline opportunities in additive manufacturing applications with an emphasis on titanium. The report identified current, emerging, and future market opportunities for additive manufacturing. Again, this report concentrated on Australia's mineral resources to process titanium in country rather than exporting raw material for processing. This report recommended the establishment of centres of excellence to conduct applied research, and offer courses and workshops on additive manufacturing.

More recently, in late 2011, the Future Manufacturing Industry Innovation Council released a report on "*Trends in manufacturing to 2020 - A foresighting discussion paper*". This report did not look at the titanium sector in detail and only had a small piece on the CSIRO TiRO™ technology and the potential to value add with downstream processes.

As can be seen, significant attention has been placed on the CSIRO TiRO™ technology as the catalyst for the establishment and growth of an Australian titanium manufacturing sector. Little attention has been paid to other downstream manufacturing technologies and capabilities across research and industry sectors, nor have opportunities, challenges or barriers facing industry participants been discussed. There is no single unifying document which describes technology / research maturity across each of the titanium production and manufacturing areas currently being researched in Australia and industry's capacity and capability to turn such technologies into commercial outcomes.

This report looks to fill this gap by developing an understanding of the degree of maturity and range of research activities across the full spectrum of technologies and processing in titanium, coupled with industry perspectives on opportunities, challenges and barriers to adoption.

1.2 Research Focused Workshop

For many years, Australia has been investing in titanium research across the full spectrum of technologies and processes ranging from extractive metallurgy through alloy development and component fabrication and production. Research activities in the Australian context are broad and varied, however there is not a direct correlation between technology maturity, research activity in a particular area of titanium development, and the degree of local industry engagement. Research efforts have, to a large degree, been driven by global indicators, whereas the capital costs and perceived enterprise risk associated with new manufacturing technologies have formed a persistent barrier to widespread industry adoption of some newer processes.

A key aim of the workshop was to develop an understanding of the degree of maturity and range of activity of titanium activities in Australia, grouped by subject matter (e.g. machining technologies, additive manufacturing technologies, etc.) rather than an attempt to rank capabilities of individual researchers, research groups or organisations.

Attendance at the workshop was open to any researcher or research organisation representative in Australia active or knowledgeable about titanium technologies. Representatives from the following research sector organisations attended the workshop:

- Advanced Manufacturing CRC
- ARC Centre of Excellence in Light Metals
- CAST CRC
- CSIRO
- Deakin University
- Monash University
- RMIT University
- Swinburne University of Technology
- The University of Queensland
- The University of Melbourne
- The University of Wollongong

Representatives from the University of Western Australia and University of Sydney were not represented at the workshop due to scheduling issues. Their views were canvassed before and after the workshop and are included in this report. Also present at the workshop were a number of State and Federal Government representatives.

The workshop provided the opportunity for each of the research institutions to present their research, with a specific focus on level of maturity and opportunities for commercial application.

Representatives from global defence prime contractor organisations (BAE Systems and Boeing) were also present as observers at the workshop and the views of Lockheed Martin were canvassed. A total of 20 participants from across these organisations attended the workshop.

1.3 Industry Focused Workshops

The DMTC conducted two one-day industry focused workshops to discuss, with industry, the opportunities, challenges and barriers to the growth of the titanium sector in Australia.

Workshops were conducted in Melbourne and Brisbane in order to gain the largest cross section of the titanium industry in Australia. Companies and individuals either working in or looking to get involved in titanium work were encouraged to participate. The groups for each workshop consisted of small and medium enterprises (SMEs), large multinationals and State and Federal Government representatives.

Companies that registered for the event included (note: a number of companies had more than one representative):

- AADI Defence
- Austrade
- BAE Systems
- Boeing
- Camplex Pty Ltd
- DMG-Mori Seki
- Enterprise Connect
- Force Industries Pty Ltd
- Haas
- ICN-Vic
- Lean Design Australia
- Lockheed Martin
- Lovitt
- Marand Precision Engineering Pty Ltd
- Rob Weller and Associates
- Rolls-Royce
- SA Government
- SEC Plating
- Snapon Tools
- Thales
- Victorian Government
- Vipac

Total Melbourne: 30

- BAE Systems
- Boeing
- DIICCSRTE
- Defence Materiel Organisation (DMO)
- DSD Innovations
- Ferra
- Haas
- Lockheed Martin Australia
- Micreo
- New Air Combat Capability (NACC) Office
- QMI Solutions
- Queensland Government
- SA Government
- SEC Plating
- TAE

Total Brisbane: 19

2 Current Australian Research Activities

The research focused workshop identified areas of research currently being undertaken by Australian research organisations and further discussed the level of overall Australian technical maturity of these activities. For the purposes of the workshop, the technology areas involved in titanium manufacturing and production were defined as follows:

- Primary Metal Production
- Fabrication
- Wrought Processing
- Injection Moulding and Sintering
- Additive Manufacturing
- Coatings
- Heat Treatment

The definition of each technology area and involvement in research by Australian research institutes are described below.

2.1 The Titanium Production Cycle

There are numerous technical areas involved in the total lifecycle of titanium, and Australian research institutions are involved in varying degrees of maturity and focus.

Figure 1 outlines the titanium life cycle in the context of activities underway within Australia.

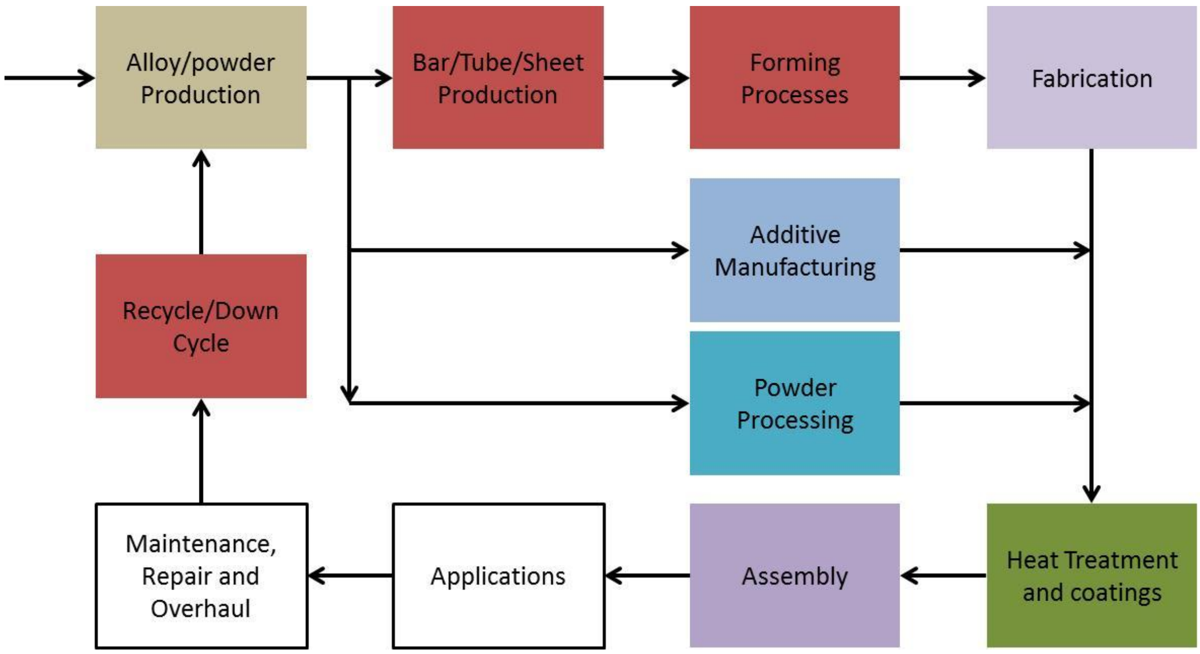

Figure 1: Representative titanium life cycle diagram. Coloured elements represent those in which Australia has active research and/or industry presence.

2.2 Primary Metal Production

The most common first step in the production of titanium metal after the ore has been extracted from the earth's crust is the production of titanium sponge. Nearly all commercially produced sponge is obtained either through the Kroll's process or the Armstrong process. The relatively high production and fabrication costs from these processes continue to limit the use of titanium metal to specialty applications. Australia does not currently have any titanium sponge production capability.

Research into the production of titanium metal, alloys and mill products via alternative processes is being undertaken by CSIRO as part of the Future Manufacturing Flagship, and CSIRO has advised that two new production processes now have a high level of maturity and are close to being considered for commercialisation. One of the developments from CSIRO is the TiRO™ process to produce pure titanium powder. In this manufacturing process, commercially pure titanium is produced from $TiCl_4$ reacted with molten magnesium. This process has been proved at a large-scale laboratory level and is capable of producing up to 2.5kg/hr of titanium powder. This process offers a lower cost continuous production which potentially replaces the batch production Kroll process that is the major source of titanium metal sponge around the world currently.

2.3 Wrought Processing

Wrought processing is most often used to describe the shaping, altering, moulding, and manufacture of various metals through rolling, forming, drawing or forging.

Deakin University has developed an improved understanding of rolling, forming and drawing of titanium which has the potential to expand the range of quality titanium alloy products available in the market. At the University of Melbourne, there is expertise in powder and recycled machining swarf titanium 'forging' using Equal Channel Angular Pressing (ECAP). Monash University also has a program utilising Continuous Equal Channel Angular Pressing (CCAP) technologies which is currently being developed through the Victorian Centre for Advanced Materials Manufacturing (VCAMM).

Most of the research work in wrought processing is in the earlier stages of technical maturity and while there has been some interest from industry, there are currently not many industry partners for this area of research activity in Australia.

Wrought processing around the world is a mature industry utilising traditional methods. Technologies Australian researchers are working on encompass new research activities aimed at developing emerging and non-traditional methods, but have poor industry links. ECAP & CCAP technologies are challenging because of scale-up issues centred on the high energy and tooling costs and components are limited to those derived from relatively small billets, although VCAMM is currently in the process of commissioning a pilot scale CCAP process.

2.4 Additive Manufacturing

Additive manufacturing is a process of making components from a digital model by depositing materials layer upon layer to produce a near-net-shape component, bypassing forming and fabrication processes and requiring only finishing processing. Additive manufacturing offers the greatest potential for reducing the waste inherent to machining processes where large amounts (typically >80%) of waste titanium are produced.

The local technical capability in this area is quite good in a research context with a large amount of research activity at Australian Universities focussed on expanding the use of titanium through development of additive manufacturing technologies for complex components. While several areas of additive manufacturing research are at an early stage, there is a good spectrum of technology maturity right up to a level close to world's best practice.

Research at Monash University uses Selective Laser Melting (SLM) of titanium alloy powder to build up complex parts or Direct Laser Deposition (DLD) of powders to build up surface features. Some of this work has been supported by the Advanced Manufacturing-CRC. Monash University also has extensive expertise in process development and application of Hot Isostatic Pressing (Hipping). CSIRO has recently purchased an Electron Beam Melting (EBM) facility (ARCAM) and is actively pursuing research activities on this basis. Similarly at RMIT University, SLM technologies are being used for developing capability to produce small high value components and for repairing selected aircraft components. At the University of Wollongong, component features are being produced additively by robot controlled shielded gas tungsten arc welding of titanium wire with excellent lab scale results. Swinburne University of Technology and the University of Western Australia also have significant capability in additive manufacturing.

To date, activity in many of the additive manufacturing areas has been driven by the research sector. While it has been necessary to develop infrastructure and obtain capital equipment to support research activities in the early stages, there seems to be a tendency for these early equipment purchases to influence research direction. The sector urgently requires a strategic approach rather than having research directions driven uniquely by supply.

The pathways for utilisation of these technologies by Australian companies are very unclear. There are varying levels of maturity for different additive manufacturing processes in Australia and there continues to be limited industry involvement. Local industry capability is at best piecewise and fragmented and certainly sub-critical mass at the present time. Although large internationals are interested and active in adopting this technology, there is very little capability in Australia at present. It should be noted that this industry utilisation gap does not appear to be related to a lack of interest in the technology, but rather some fundamental barriers to uptake, relating to scale, low experience base, investment requirements, long lead times to contract and/or absence of orders and the timeframes required for moving the technology onto the shop floor, to name a few.

With the advent of additive manufacturing techniques holds the promise of powder based components which greatly increase yields, improved fabrication processes and the like, applications previously considered too costly could now prove attractive if approached from a full life cycle perspective.

Additive manufacturing technologies present perhaps the greatest challenge for Australia, in that they represent the areas of activity with the greatest mismatch between technology maturity and industry engagement. This is broadly reflective of the global situation given that additive manufacturing technologies are relatively new, however Australia remains considerably behind world’s best practice in terms of industry utilisation of the technology. While there are isolated examples in Australia of industrial uptake of this technology, there is limited national capacity and the overall level of industry engagement with this technology in Australia is quite weak and patchy.

Security of supply for precursor powders is also likely to become a factor as additive manufacturing methods mature, and Australia should consider whether a local capability should be established in this regard. Precursor powders for additive manufacturing applications are tailored to the application and there has been considerable global effort directed towards this area in recent years. Without a local production capability in this area, this may prove to be a considerable price point constraint to the future development of this group of technologies.

2.5 Powder Processing

Powder processing research in Australia is primarily focused on injection moulding and sintering activities. Injection moulding is a manufacturing process in which materials are fed into a heated barrel, mixed and forced into a mould cavity. Sintering is a process through with powdered material is placed in a mould and then heated to a high temperature below the melting point. The powder particles fuse together and create a component in the shape of the mould.

The University of Western Australia and the University of Queensland are conducting research programs to produce low cost components through compaction, injection moulding and sintering. This technology holds the promise of providing near net shape components for a broad range of applications.

As with other titanium research areas, Australia enjoys good research capabilities in this area, but this is offset by the relative lack of industry linkage.

2.6 Fabrication

Fabrication technologies include cutting, bending, welding or assembling processes in order to produce components of different shapes and sizes. For the purpose of this report, casting has also been included under fabrication.

Considerable expertise has been developed at the University of Queensland, the CAST CRC and DMTC in advanced titanium machining technologies. This work has involved partnerships with a number of Australian machining companies. Swinburne University of Technology also has active research in this area. Some of the work initially managed by the CAST CRC in the area of laser assisted machining will also continue in future years with coordination by CSIRO and involvement of RMIT University and CAST.

The University of Wollongong has extensive expertise in advanced welding processes including capability in the welding of titanium alloys. Swinburne University of Technology is also undertaking research in laser deposition of titanium for component repair.

Many research organisations including Monash University, Deakin University and The University of Queensland have expertise in microstructural control and alloy design of titanium alloys particularly through the ARC Centre of Excellence in Light Metals. The University of Queensland has expertise in the small scale fabrication casting and solidification of titanium alloys and projects in laser welding with medical device applications and industry partnerships with medical component manufacturers. Swinburne University of Technology has expertise in the development of titanium materials for biomedical applications and the University of Western Australia is also developing technologies for potential biomedical applications.

There are currently a number of partnerships between research and development (R&D) providers and Australian manufacturers in the area of titanium machining. A number of Australian companies are machining titanium components and supply to the global aerospace market. There are also some partnerships between R&D providers and companies in the area of titanium castings.

Australia currently enjoys a relatively strong linkage between research and industry in fabrication, however it should be noted that there is typically a need for new research when new processes are developed or a process is applied to a new component. Fabrication technologies in Australia have a track record of rapid integration into industry, however the link between alloy design and industry capability is generally poor.

2.7 Coatings & Heat Treatment

A coating is a process of covering the surface of a component to order to improve surface properties. CSIRO has developed a cold spraying technology for titanium coating of other materials which is now also being used for additive manufacturing. Research at RMIT University into coatings/cladding utilises their laser melting facility. Swinburne University of Technology has research capability in thermal spray technologies which could be applied to applications involving titanium alloys. Significant progress has been made in the R&D of new biomedical titanium alloys and alloy scaffolds for use in load-bearing applications, such as bone and joints replacements at Deakin University. New classes of titanium alloy coatings have been developed for implant applications at Deakin University, Swinburne University of Technology and Queensland Universities.

Cold spray technology is in a relatively mature state and has been adopted by a number of companies in Australia. Noting that while capacity remains an issue as with many activities in Australia, local industry capability is assessed to be quite strong in this area. There is also industry activity in applying established coating processes to current emerging aerospace components (i.e. for the Joint Strike fighter program). The research sector is focusing effort on alternatives to these processes, many of which are electrochemical and present considerable occupational health and safety and environmental risks, however to date, these alternatives have not been developed to sufficient maturity for widespread industrial application.

Heat treatment processes involves the targeted application of elevated temperatures in order to impart a desired microstructural change and thus modify the mechanical properties of the material to achieve a desired property set. Heat treatment is an important enabling technology for both titanium component manufacturing and repair, and is also an area with some existing Australian capability.

Through the DMTC, the University of Queensland has been working with Australian industry to develop local titanium heat treatment capability. Heat treatment may also play a significant role in direct manufacturing technologies.

2.8 Summary

The following table summarises the areas of expertise in each of the Australian Universities actively working in the different areas of titanium technology research discussed above.

Table 1: Summary of scope of Titanium component production research activities underway in participating Australian research organisations

	Primary Metal Production	*Fabrication*	*Wrought Processing*	*Injection moulding and sintering*	*Additive Manufacturing*	*Coatings*	*Heat Treatment*
The University of Queensland		✓	✓	✓	✓	✓	✓
The University of Melbourne			✓				
Swinburne University of Technology		✓			✓	✓	
RMIT University		✓			✓	✓	
CSIRO	✓	✓	✓	✓	✓	✓	
CAST CRC*		✓	✓				✓
DMTC*		✓			✓		✓
The University of Wollongong		✓			✓		
The University of Western Australia		✓		✓	✓		
Deakin University		✓	✓			✓	
Monash University		✓	✓		✓		
ARC Centre of Excellence in Light Metals			✓	✓	✓		✓
Advanced Manufacturing CRC*		✓			✓		

3 Industry Opportunities, Challenges and Barriers

Two industry focused workshops where conducted to canvass the ideas of the industry sector. Participants were given an overview of findings from the research focused workshop and invited to discuss opportunities, challenges and barriers facing the titanium sector in Australia.

3.1 Opportunities

Opportunities for growth in the titanium sector discussed during the workshops included:

- sectors that would benefit from titanium products in their supply chains;
- machining and fabrication innovations; and
- additive manufacturing.

Industry Sectors

Opportunities in defence and aerospace are typically the focus of conversations with respect to the titanium sector, however, due to its high strength to weight ratio and resistance to corrosion, other opportunities exist for utilising new titanium manufacturing technologies in areas such as medical devices and implants, food and wine, consumer and marine applications. Future resource projects such as geothermal energy would also find the properties of titanium highly beneficial if production costs can be reduced through new higher yield technologies currently under development (such as CSIRO's TiRO™ technology).

Opportunities in international aerospace programs was an obvious area of interest in discussions due to the increase in titanium use in aerospace structures. One such example of the increased use of titanium in aerospace platforms is the Boeing 787 program. Legacy aircraft have approximately 1-2% titanium by airframe weight, the Boeing 787 has increased this to 14%. Direct and additive manufacturing technologies are expected to play a large role in increased use of titanium in airframe manufacture and sustainment along with improved fabrication and machining technologies.

Maritime applications were also identified as an area of potential growth for titanium components. Discussions centred on the replacement of existing components with titanium due to its superior corrosion resistance. General maritime structural components were identified as well as underwater electrical connectors and sonar applications. Opportunities in maritime platforms and weapon systems would most likely be through large international prime contractors.

Medical applications were identified as a growth area that could utilise titanium's material characteristics. Significant investment is being spent designing medical devices and components utilising titanium. Additive manufacturing has been identified as key to expanding this sector due to its ability to create previously non-machineable parts for applications in dentistry and joint replacements.

Other potential areas of growth include:

- Industrial chemical applications for corrosion protection;
- Food processing applications for improved protection against unwanted chemical reactions;
- Sporting equipment and the possibility of using lower grade titanium (possibly waste and recycled material) for a range of sporting applications; and
- Automotive: it was identified that overseas companies are looking at automotive applications closely, but fabrication and material costs are still an issue.

Global supply chains and the opportunity for Australian SMEs to join such programs were also discussed. In the defence / aerospace sector, Lockheed Martin and Boeing have programs that look to link Australian SMEs into supply chains of their larger programs and these were considered a positive for the industry. Furthermore, the 2013 Defence White Paper highlighted international engagement opportunities for industry through "…*Defence will continue to assist companies to access information on working with prime contractors and obtaining advice on how to become more competitive. This is being achieved through a range of initiatives, including the Australian Military Sales Office, which assists with export opportunities and increasing industry capacity…*" and "…*the Government has strengthened the Australian Industry Capability Program, which aims to maximise opportunities for Australian industry to participate in domestic and international supply chains, under defence capital equipment acquisition program contracts*."

Machining and Fabrication Innovations

Machining of titanium components for the aerospace and defence sectors counts for the majority of titanium manufacturing activity in the country (particularly for SMEs).

It was noted that increased competition in supply chains for titanium machining (e.g. tooling, automation, etc.) has resulted in significant innovations in this field in the last couple of years. Some of these innovations include reduced cutting tool costs through automation and tool life predictions, allowing for 24/7 factory operation at reduced costs. This has allowed businesses to remain competitive with lower cost economies.

Arguably, the largest area of opportunity relates to waste titanium from machining, often >70% and up to 95% for aerospace components. Whilst this is a major challenge for the sector, the ability to deal with waste chips was seen as a huge opportunity. Currently, to recycle titanium chips, companies need to be able to guarantee quality and moisture content of their chips before being sent to a blast furnace or compactor. Implementing such control / process measures is not economically viable for most businesses, therefore most of the waste is sent to China for processing. Participants pointed out that these stringent requirements are required to produce high grade titanium from the waste product suitable for industries such as defence and aerospace. A potential opportunity was discussed to utilise lower grade titanium waste for other sectors with less stringent requirements such as sporting equipment.

Additive Manufacturing

As discussed above, waste from the process of machining titanium is a huge issue for the sector. Additive manufacturing has the potential to address this issue by creating near net shapes and reducing the amount of post processing required. Opportunities for additive manufacturing also exist in its ability to create non-machineable parts.

Whilst there are significant opportunities, there are some commercial opportunities to overcome. These include certification and qualification of materials and components produced with additive manufacturing techniques. The maximum size of components able to be produced is also a limitation.

Other areas of interest, particularly for the multinational aerospace and defence companies include:

- material properties of both components produced from additive manufacturing and the feedstock for such processes;
- non-destructive testing of additive manufacturing components;
- the development and use of nano-composites involving titanium;
- high temperature materials; and
- titanium honeycomb structures not previously machineable.

3.2 Challenges and Barriers

There are many opportunities for the growth of the titanium sector in Australia, however, the industry also faces a number of issues. Discussions included:

- the need to develop business cases for opportunities in the titanium sector to allow for private investment from industry;
- waste and recycling;
- competition with low cost economies; and
- qualifications.

Business Case Study

The discussion of challenges and barriers for the titanium sector centred on investment rationale. It was highlighted by industry that there is a need to demonstrate a sustainable business case in order to consider investment in new opportunities, markets, technologies and processes. Industry and Government alike need to have an economic understanding of what is viable and what is sustainable to identify what is worthy of investment or government intervention in areas of market failure. This not only includes the market data behind various opportunities, but an overall understanding and mapping of opportunities. Technology road-mapping would be a useful tool in this respect to map out and understand long term industry strategic goals and the short term technology requirements required to meet these goals. This will allow for an informed national strategy to be developed.

Whilst the development of such a business case for the sector is of utmost importance for Government when considering investment into a particular sector, SMEs need to understand the fundamental questions around "what is the opportunity and what is the market?". New opportunities and technologies need to be linked to; the size of the market, market trends, competitor analysis, etc. before an informed business case and investment decision can be made.

Traditionally, SMEs are not in a position to access this information, whether it be financial constraints involved with accessing quality market data, analysis or an understanding of the market itself or resources required to conduct the research. The flow on effect is that businesses cannot make informed investment decisions without a fundamental understanding of the business case opportunity. A number of Government programs exist to help businesses through this process, e.g. Enterprise Connect and Commercialisation Australia.

Apart from the business case investigation mentioned above, other areas that were identified in discussions included:

- tool makers need to understand industry trends in machining and tooling requirements to develop the next generation of titanium manufacturing tools;
- the difference in business cases between high grade titanium (aerospace / defence) vs lower grade (automotive / sporting equipment) markets;
- opportunity sensitivity analysis with respect to the price of titanium, what opportunities may exist if the price of titanium reduces?;
- understanding barriers to entry and associated costs, i.e. qualification and certification for aerospace applications; and
- reviews of previous and current titanium industry strategies (i.e. what has been done, what value did it provide, what can be improved, etc.).

Competition with low cost economies

In today's economic climate, any study related to Australian manufacturing needs to assess competition with low cost economies. Traditionally, titanium has been protected as a specialised area due to cost and skill barriers. However, as low cost economies develop, their understanding and skill in working with titanium is dramatically increasing.

It was noted that Australia is on par technically with competitors around the world, however Australian labour and business costs are typically ~30% more expensive than comparable low cost economies. This means that Australian businesses need to invest in automation, manufacturing efficiencies and technology innovations to remain competitive.

A number of manufacturers stated that there are good barriers to entry in industries such as defence (nationality restrictions) and aerospace (qualifications and certification) which mean that Australian SMEs can remain competitive on the international market. However, medical and automotive sectors are trade exposed to China and India. In this respect, several machine suppliers and tool makers noted considerable amounts of work heading offshore. One international tool maker stated that China is now their biggest customer out of the US because China cannot make enough machines in country to supply their own industry.

Certification and Qualification

It was stated above that qualifications and certifications in the aerospace sector provide a good barrier to entry and protection from low cost economies, however this also causes considerable issues for Australian businesses both in cost and expanding into new markets. Qualifications and certifications, particularly for the aerospace sector, place considerable burdens on SMEs that impact resources, profitability and productivity.

3.3 Areas of Interest for Defence Primes

Defence Primes and aerospace Original Equipment Manufacturers drive many market segments in titanium and therefore technology uptake. As part of the industry workshops, these organisations were surveyed to gain an understanding of their drivers in this segment.

Below is a list of general areas of interest as identified by defence primes in the workshops:

- Additive Manufacturing
    - Direct manufacturing for aerospace, biomedical and others.
    - Additive manufacturing for non-machineable parts.
    - Applied research in the areas of additive manufacturing; material properties, NDT, nano-composites, high temperature materials and titanium honeycomb.
- Tooling and machining
    - Improved fabrication / improvement in fabrication technologies.
    - Tool life extension.
    - Improvements in cutting tools, machining selection and programming.
    - Research into vibration in machining.
    - Supporting spacing for larger and complex parts.
    - Cutting of titanium to align with cutting times of aluminium.
    - Close form forging to reduce waste.

- Material Characteristics
    - Improved performance of titanium material, alloy density, static strength, surface performance under high temperature.
    - Lower cost of raw materials, buy to fly ratios, material waste and removal.
    - Memory shaping titanium for aerospace applications.
    - Corrosion resistance for maritime components.
    - Weight reductions.
    - Blast / ballistic protection.
- Benchmarking of SMEs is seen as important to primes in developing supply chains.

This list of market drivers aligns strongly with both the discussion on current Australian research capabilities (see Section 2) and opportunities identified by industry. Opportunity therefore exists for international investment in aligned areas of research with local supply chain involvement. This would have flow on benefits of keeping Australian companies more competitive and provide additional opportunities in international markets.

4 Transfer of Research into Industry Capability

Industry engagement with titanium technologies and research is a critical issue and must be considered as part of a technology development and investment strategy for government, industry and research sector organisations.

4.1 Technology Maturity and Industry Engagement

The level of maturity and potential application of various titanium technologies at various stages of the life-cycle outlined in Figure 1 were discussed. The results of this discussion and consultations with the sector are illustrated in Figure 2, which represents an estimation of the relationship between the technology/research maturity and the level of industry engagement in each technology. It must be noted that both are considered in an Australian context alone, and represent a qualitative assessment of the range of technology maturities and levels of industry engagement.

Figure 3 compares the assessment of the state of maturity of Australian activities with that of global best practice, again based on discussions in the workshop and additional consultations in the sector. A range of interpretations can be inferred from discussion and information provided to underpin Figures 2 and 3:

- Australian technology development activities in titanium cover a broad range of the titanium life-cycle and in most cases represent a wide degree of technical maturities. In general, the range of technology maturities is reflective of a process of renewal and updating of established technologies, and also indicates the process of process-specific research that is undertaken to transfer a research capability into an industry capability, even within an established technology area.

- Australian research and technical activities are broadly consistent with global best practice in fabrication technologies (such as machining, welding and casting), and close to best practice in heat treatment technologies, but remain some way behind best practice in other areas.

- In many areas, Australian technical maturity is generally close or equivalent to that of global best practice and in many cases it is likely that technology maturity gap could be bridged by greater industry engagement. The main exception is in wrought processing where Australia seems significantly behind global best practice both in terms of industry engagement and technical maturity. Although it should be noted that global industry engagement for ECAP processes remains relatively low. Wrought processing research in Australia has moved beyond the routine processing pathways which are now practised primarily in developing economies and not areas where Australia can compete on cost, into more sophisticated examples of the technologies.

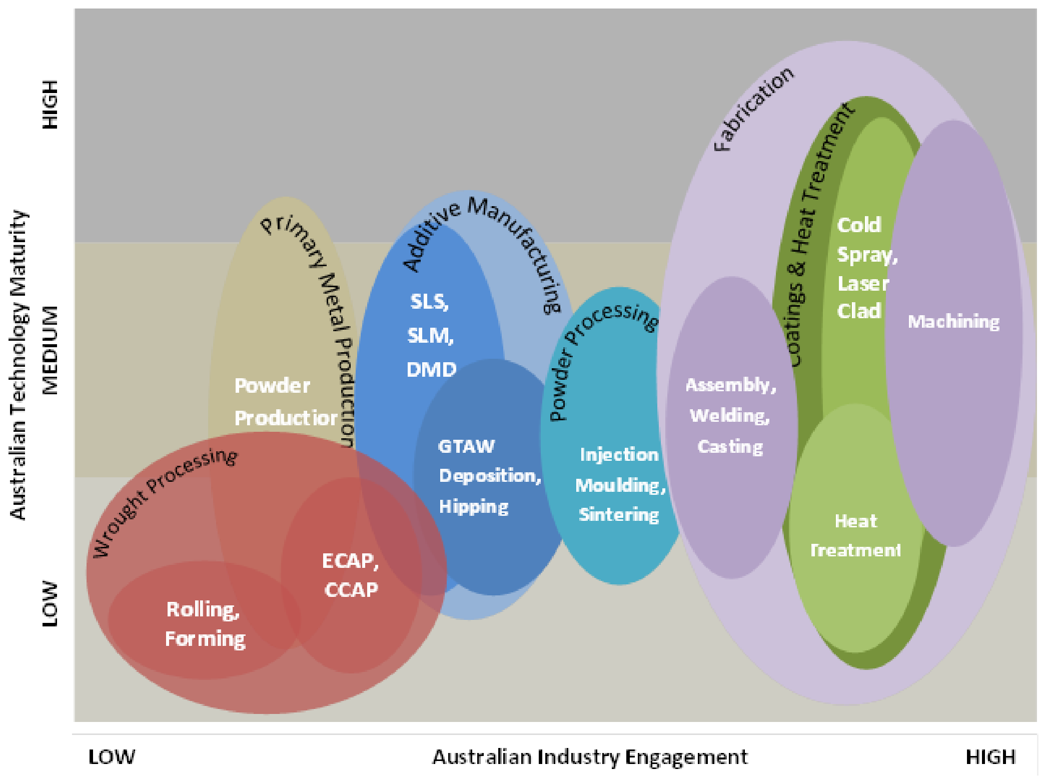

Figure 2: Illustration of Australian technology maturity against Australian industry engagement for the range of titanium technologies considered. Colour codes are grouped to correspond to the titanium life cycle elements represented in Figure 1.

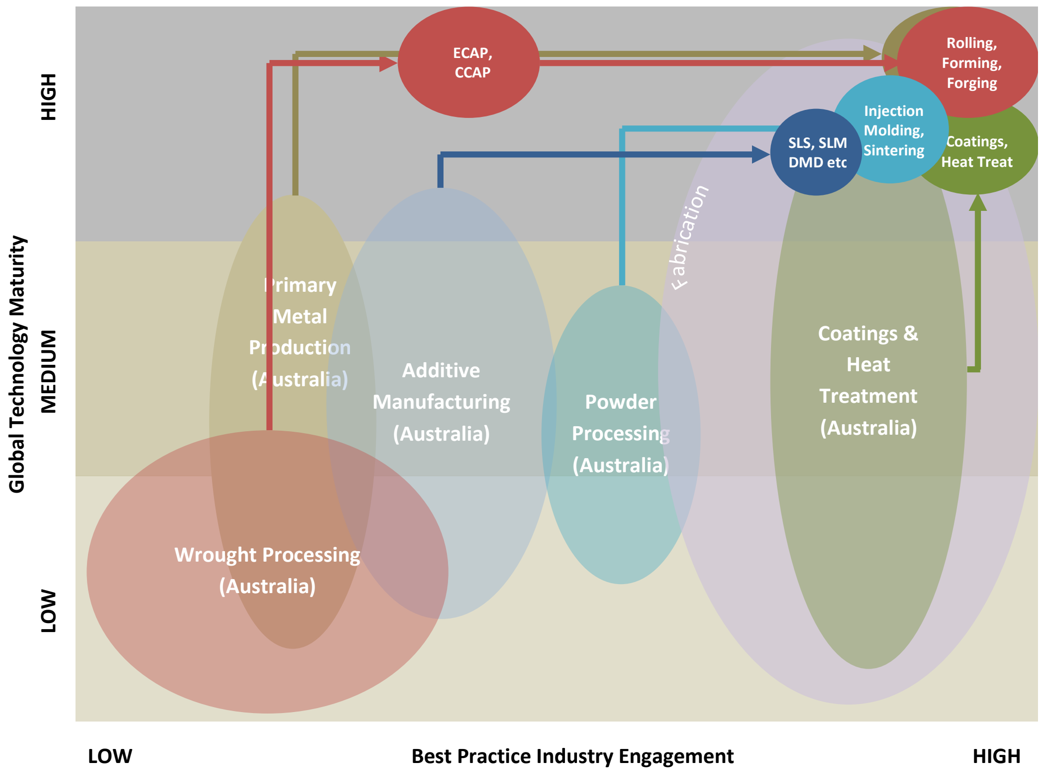

Figure 3: Comparison of Australian technical/industry-engagement maturity with global best practice for the range of titanium processes considered. Colour codes are grouped to correspond to the titanium life cycle elements represented in Figure 1.

4.2 Commercialisation and Technology Transfer

In the context of the titanium sector, some titanium technologies are mature, while others can be classified as being at an emerging stage of development and integration into industry. At this point of an emerging sector life cycle, particularly in a high technology industry, market forces are traditionally a mixture of market pull and technology push. In the early stages, research and technology breakthroughs necessitate a technology push approach as industries are educated as to the benefits to their market segments. This is no more evident than in the additive manufacturing space. It is not until a critical mass of capability and knowledge is reached that the industry will be market pull driven with significant growth and sustainability resulting.

Generally, commercialisation of technologies has traditionally involved technology-push approaches through research organisations that have developed the particular technology. Commercialisation in recent years has proven the worth of demand driven or “market-pull” strategies. Market-pull commercialisation offers greater opportunity for successful commercialisation of new technologies because it takes into consideration the needs of the market represented by businesses involved in product and services development. This explains the focus of discussions in the industry workshop for the need to understand the business case behind new technologies and entering new market segments.

Furthermore, it must be noted that it is not always product innovation that creates growth and sustainability for businesses. Market innovation allows firms to leverage existing resources, better understand markets and expand into new or adjacent markets. Therefore, successful commercialisation of the research and technologies discussed above will be dependent on coupling product and technology innovation with the appropriate business model to fulfil the needs of the market and in addressing existing problems and challenges. Additive manufacturing falls into this category as it has the potential to change existing manufacturing business models and supply chains (e.g. on demand, on site, near net shape component replacement and repair).

4.3 Collaboration between Research and Industry Sectors

While research and industry capability is represented in Figures 2 and 3, Australian activity has capacity limitations due to the overall size of the sector and number of organisations. This places critical mass issues on the sector that affects collaboration between research and industry sectors. Even in areas where industry capability is high (such as fabrication), the capacity of industry is limited. As a result, opportunity exists for local industry to collaborate with international partners to expand capability and capacity and also gain access to international supply chains. Increased international investment has the ability to migrate Australian industry to world-best practise in many areas of the titanium sector.

As discussed throughout this report, there are aspects of the titanium sector that are currently in a technology push phase which means that the collaboration between research and industry sectors is of utmost importance to ensure research and technology development is directly coupled to market opportunities.

Collaboration between industry and academia is an important driver of national innovation capacity and increasing the impact of research outcomes. Collaboration is a key component of open innovation whereby organisations use both internal and external knowledge and resources (a key driver for SMEs who are typically time and resource poor) to drive and accelerate their internal innovation strategy in order to fulfil existing market needs or to access new market opportunities.

4.4 Absorptive Capacity

Anecdotally, there are a broad range of Australian SMEs who, if made better aware of the advantages of titanium, the advances being made in its fabrication and new manufacturing technologies and if a commercial viable business case was presented, could provide a local utilisation pathway for the research. However, as discussed above, the sector does suffer from critical mass related issues with SMEs that are time and resource poor. In this respect, absorptive capacity of businesses becomes a key driver of the adoption of new technologies.

Absorptive capacity of an organisation is defined as its ability to recognise, exploit and integrate external knowledge for its own use. A firm's prior related knowledge enables it to recognise valuable new information, assimilate it and apply it to commercial ends. Therefore, a firm with a better developed knowledge base in a particular field or a firm that subscribes to the open innovation model to leverage existing resources will have a higher absorptive capacity for new opportunities.

A key aspect of absorptive capacity is the ability to recognise an opportunity arising from new knowledge about technology, a customer's needs, or market trends. Companies are better placed to uptake technology when it possesses the absorptive capacity to recognise the potential value created from the exploitation of the new technology in servicing the needs of customers and the market.

From discussion with both the research and industry sector, a key area of importance to drive the growth of the titanium sector lies in the dissemination of information on the current research activities being conducted in Australia, coupled with potential applications and market opportunities to allow business to make informed business case decisions to adopt, invest or develop a new technology.

4.5 International Investment

Workshop participants highlighted that a number of international aerospace companies have supported and will likely continue to support research activities being undertaken in Australia in titanium, particularly additive manufacturing. International companies have also directly supported Australian SMEs in technology development projects with the opportunity to connect companies with international supply chains if projects are successful. Further opportunity exists for local industry to engage with international companies on technology development projects, particularly in areas where Australian research has shown to be world's best practise.

Workshop delegates also found it encouraging that international aerospace companies have supported research in Australia and saw it as recognition of the quality of research being undertaken. A small number of domestic SMEs have also supported individual research projects and researchers and CSIRO has now financed its own discrete program within the Future Manufacturing Flagship from internal resources and hope to recoup this investment through future licensing or other IP sales.

While there are several examples of international companies being prepared to support research in Australia, the government is keen to see this grow. For this to be successful in an Australian context, collaboration with the local industry sector through a supply-chain or similar teaming arrangement will need to be considered and built into research activities and investment decisions.

4.6 Government Assistance

The majority of titanium technology research remains heavily reliant on Australian competitive granting schemes. The competitive structure involved in securing funding for research means that a coordinated approach to advancing the most commercially viable technologies has yet to be taken, and that conflicting technologies are being developed in parallel. While this is to be expected at this point in an industry's life cycle, and perhaps even encouraged to a degree as new frontiers in the technology are explored, there remains a strong disconnect between the research capability and industry adoption. This is a common trend in an early stage life cycle industry such as titanium that is transitioning from a technology push to market pull scenario.

These factors present a sector which, although highly capable in key areas, continues to face considerable challenges in terms of matching technology supply and demand in a local context, and which will in likelihood continue to be informed by global trends and drivers. Continued investment in building research capability means that this sector is expected to remain competitive on the world stage in particular areas. Therefore, a key driver to the growth and sustainability of the industry sector will be that timely and relevant research has a mechanism to be transferred into industry. These factors frame the discussion on future investment in titanium technologies for government, industry and research sector organisations, and provide a key starting point for future discussions with the Australian industry sector.

The government also provides support through various programs focused at addressing areas of market failure. With the titanium sectoring being at an emerging life cycle stage, many of these support programs are directly relevant to the sector and the research and industry sector are encouraged to utilise these programs:

- A Plan for Australian Jobs – The Australian Government's Industry and Innovation Statement
    - Backing Australian firms to win more work at home: support capabilities of Australian firms to win work from Australia's major projects and global supply chains.
    - Supporting Australian industry to win new business abroad: $500m investment in innovation precincts and $50m per year for the Industry Collaboration Fund and Industrial Transformation Research Program ($236m).
    - Helping Australian small and medium businesses to grow and create new jobs: building capabilities to assist growth, business capabilities and innovate.
- Enterprise Connect: Advice and support to SMEs to help them reach their full potential.
- Researchers in business: Support the placement of researchers from universities or public research agencies into businesses.
- Commercialisation Australia: Assisting researchers, entrepreneurs and innovative companies to convert ideas into successful commercial ventures.
- Global Supply Chain: Assist Australian defence industry with opportunities made available in international business units of large international companies.
- Cooperative Research Centres (CRC): End user driven research collaborations, $50m allocated to support manufacturing focused CRCs.
- R&D Tax Support: Helps businesses offset some of the costs of doing R&D.

5 Recommendations

After consideration of the discussions held at the workshops, the advancement of the titanium industry and titanium technologies is thought likely to follow a trajectory whereby research sector organisations continue to develop technical capability and approach industry engagement and commercialisation of their individual technologies in discrete activities individually. While this would continue to grow research capability and technology maturity in each area, it would almost certainly result in Australia maintaining a low to medium level of industry capability in titanium technologies, driven by fragmented opportunity and without any broad coordination or capacity. Whilst this is expected for an emerging industry sector, greater coordination across the sector will be required to achieve significant sector growth.

A national approach incorporating a coordinated, strategic development pathway for selected titanium technologies, based on informed business case assessments could ensure stronger industry engagement and lead to better development outcomes of greater commercial application. This would require a long term commitment and coordination between various State, Commonwealth, industry and Research sector organisations.

To increase industry pull in titanium technology research, a coordinated approach to informing industry about technology developments and transfer of technology to industry is required, as a means of advancing capability on a sector-wide basis. For both SMEs and larger manufacturers, the identification of the most appropriate research partner and the management of a research activity can be difficult, and in the case of single-partner engagement may not provide a comprehensive solution to the technology demand. This is a particular issue for SMEs where resources are precious and capability to absorb new technology at the enterprise level may be sub-optimal.

In this context, some key activities have been identified which will support increased industry engagement with titanium technology development, as outlined in Table 2.

Table 2: Some key elements identified by the workshop participants to include in future technology investment models

Activity / Investment model feature	⇨	Outcome
Linking SMEs with research expertise, networks and international companies	⇨	Technology transfer to industry, reduced time, cost and potentially ineffective partnerships for the SME, supply chain opportunities
Actively embedding SMEs into local and international supply chains	⇨	Increased supply chain opportunities, robust relationships, embedded technology
Facilitating R&D activities which are of direct relevance to the customer, including international partners	⇨	Increased contract opportunities for SMEs, support for future customer requirements
Developing cost efficient research and development models via networks and collaboration (both domestically, and abroad)	⇨	Greater commercial gains for SMEs per dollar invested, strong leverage of SME investment with network participant investment
Development of business cases for various technology opportunities and market segments, including international supply chain opportunities	⇨	Implementation of an informed national strategy and policy based on viable and sustainable opportunities
Investigation into the establishment of a peak body for the titanium sector	⇨	An industry champion and advocate to drive the development of the titanium sector in Australia

The recently released *Future Manufacturing Council: Trends in manufacturing to 2020* discussion paper further picks up on these themes and confers the key elements that manufacturing firms will need to remain resilient and robust, and is of direct relevance to any mechanism to develop stronger links between titanium research and industry adoption. Table 3 summarises the key points that have been discussed in this paper, aligned with the key elements that the Future Manufacturing Council deemed necessary for the future of manufacturing in Australia.

Table 3: Relevant key recommendations from Future Manufacturing Council with suggested investment model features for future technology development support

Future Manufacturing Council key elements for a resilient and robust manufacturing industry	Required Research Activities
Recognise that to succeed in the high value-add, low volume products in which they are likely to have a competitive advantage, they must bundle products and services to sell solutions, rather than simply tangible products.	Facilitate the development of complete solutions through the supply chain, including international supply chains.
Have the capability to identify, design, develop, make and sell products and services that are in demand.	Align R&D activities with both local and international customer demand
Operate with high efficiency and productivity, allowing them to optimise the use of their capital – human, intellectual and material	Focus activities strongly on increasing productivity
Have the ability to maximise leverage from strong and sustainable partnerships through local and global supply chains	Embed SMEs in supply chains and technology development projects
Seek markets in emerging growth economies, both by partnering in global supply chains, and by meeting demands from their growing middle classes for high value add niche products, rather than low cost commodities	Create and develop niche and in demand capabilities that are linked to global supply chains

It is recommended that the following short-term activities could provide much needed assistance in focusing national effort in this area:

- A regularly updated repository or communication of research activities and expertise be made available to be accessed by interested parties (research sector, industry sector, etc.).
- Consideration should be given to developing collaborative initiatives that draw together the high quality capabilities identified at the workshops in an integrated fashion. These initiatives should have a broad manufacturing focus with a major titanium program rather than being a stand-alone titanium initiative. This would also reduce the confusion regarding the different types of technologies currently being researched, and which one is likely to be the 'successful' one for each application type.
- The identification of domestic and international demand for titanium related capability should to be undertaken in a coordinated manner. This should address areas for application across all industry areas.

6 Acronyms and Glossary

- Additive Manufacturing: Making components from a digital model by depositing materials layer upon layer to produce a near-net-shape component.
- Castings: Liquid material is poured into a mould which contains a hollow cavity of the desired shape, and then allowed to solidify.
- CCAP: Continuous Equal Channel Angular Pressing.
- Cladding: The bonding together of dissimilar metals as a method to fasten metals together.
- Coatings: Covering the surface of a component to order to improve surface properties.
- Cold spraying technology: The build-up of material using materials that remain at or near room temperature until impact with a substrate, usually at supersonic speeds, to form a metallurgical bond.
- CRC: Cooperative Research Centre.
- DMD: Direct Metal Deposition.
- DMTC: Defence Materials Technology Centre.
- DIICCSRTE: Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education.
- EBM: Electron Beam Melting. The manufacturing of parts by melting metal powder layer by layer with an electron beam in a high vacuum.
- ECAP: Equal Channel Angular Pressing. An extrusion process to refine the microstructure of metals and alloys by extruding metal around a corner.
- Fabrication: Cutting, bending, welding or assembling processes in order to produce components of different shapes and sizes.
- GTAW: Gas tungsten arc welding.
- Heat Treatment: The targeted application of elevated temperatures in order to impart a desired microstructural change and thus modify the mechanical properties of the material to achieve a desired property set.
- Hipping: Hot Isostatic Pressing. A manufacturing process to reduce the porosity and increase the density of metals and ceramic materials.
- Injection moulding: Materials are fed into a heated barrel, mixed and forced into a mould cavity.
- Laser cladding: Powdered or wire feedstock material is melted by use of a laser in order to depositing material onto a substrate.
- Primary Metal Production: The production of titanium sponge, typically through the Kroll's process or the Armstrong process.
- Sintering: A process through which powdered material is placed in a mould and then heated to a high temperature below the melting point.
- SLM: Selective Laser Melting. Using a high powered laser beam to create three-dimensional metal parts by fusing fine metallic powders together.
- SME: Small and Medium Enterprises.
- Thermal spray technologies: The build-up of material using materials that are melted or heated before being sprayed onto a surface.
- TiRO™: A CSIRO developed process for direct production of titanium metal powder involving the continuous reduction of titanium tetrachloride with magnesium.
- VCAMM: Victorian Centre for Advanced Materials Manufacturing.
- Wrought Processing: Shaping, altering, moulding, and manufacture of various metals through rolling, forming, drawing or forging.

7 Titanium Industry Report References

Reviews and studies that explore various aspects of titanium research, production and manufacturing include:

1. Australian Government - Department of Industry, Tourism and Resources, Aug 2001, “Australia Leading the Light Metals Age”, Light Metals Action Agenda - Strategic Leaders Group

2. Hogan, L., McGinn, E., and Kendall, R., March 2008, “Research and development in titanium - implications for a titanium metal industry in Australia”, ABARE

3. CSIRO, March 2011, “Additive Manufacturing - Technology Roadmap for Australia”, Wohlers Associates

4. Australian Government – Department of Innovation, Industry, Science and Research, Sept 2011, “Trends in manufacturing to 2020 - A foresighting discussion paper”, Future Manufacturing Industry Innovation Council