INSIGHTS PAPER

Advanced Materials and Manufacturing

INTRODUCTION

New and improved materials are being discovered and developed at a rapid pace. In the next 15 to 30 years, advanced metals and composites will become increasingly available in strong, lightweight structures, while applications of nanomaterials, metamaterials, superconductor and self-healing components will have emerged. Advances in manufacturing techniques will underpin new technologies and the use of these materials, with additive and hybrid manufacturing making more efficient, lower waste products, highly customised design and production, and embedded electronics and sensors. The application of these technologies is the primary focus of the Emerging Disruptive Technology Assessment Symposium on the future of Advanced Materials and Manufacturing (AM&M).

In realising and adopting the technologies of the future, society will navigate many challenges. Technological advances may see a rapid proliferation of new products, vehicles and components that government policy and regulation must cover. It will also present opportunities and risks for Australia's society and economy. Australian technology companies and manufacturers will have opportunities to design, produce and sell high value, niche products and materials, causing new demand for skills and applied research. Alternatively, Australia may fall behind if education, research and government policy cannot support these shifts in the economy.

In the context of Defence, the more rapid development of new technologies and deployment of new capabilities present both an opportunity and a threat. The rate of development in materials and manufacturing will require Australia to be able to quickly adopt, or quickly counteract, new technologies and capabilities. It also presents an opportunity to more easily build sovereign capabilities and to insert more Australian suppliers into the Defence sector by developing high value, specialised components.

There are many potential implications concerning AM&M:

- How will trust and assurance be maintained with the proliferation of new materials and manufactured products?
- Will we be prepared to accept new manufactured products without rigorous testing and validation in order to more rapidly progress technology?

On the development of Defence capability:

- How do we increase the pace at which new materials and manufacturing technology are identified and adopted in Defence capabilities?
- Where can agile manufacturing and rapid design and build approaches be applied in Defence capability? Can testing and verification be streamlined to facilitate advances in materials and manufacturing?
- How can Australia maximise its domestic capabilities in Defence-related industries?
- How can collaboration between Defence, research bodies and industry best enable the exploitation of new technologies in advanced manufacturing and materials?

On the impacts to Australia, its security and its economy:

- Can Australia's government, businesses and workers embrace the changing industrial environment, or will we fall behind?
- Can Australia's own natural resources lead to a strategic advantage in the development of advanced materials and manufacturing?
- What strategic risks do we face from reliance on expensive, rare or imported resources in advanced materials and manufacturing?

- How can Australia foster high value industries and capture a greater share of the manufacturing value chain?
- How does Australia deal with the new and continually changing threats posed by advances in materials and manufacturing?

Insights Paper Aim and Scope

As the agency responsible for leading the development of Defence technological capabilities, Defence Science and Technology (DST) Group has a direct interest in AM&M and how to best understand the opportunities and the threats it presents. This Symposium will explore AM&M opportunities and challenges with a view to identifying key themes for future research, industry focus and joint experimentation to inform Defence capability out to 2040. A key output of the Symposium will be a Big Picture Analysis Report that captures the contributions of Symposium attendees. The first step in the EDTAS process is an initial engagement with stakeholders to develop 'insights' that will inform the design of the Symposium workshops.

In developing this Insights Paper, DST Group and Noetic conducted 24 interviews in Australia with scientists and academics from a range of relevant disciplines, industry leaders and Defence staff. Those interviewed were either engaged in research areas that inform potential AM&M solutions and opportunities, or are in roles that consider and make decisions about the capability aspects of these matters. Stakeholders provided a wide range of insights into AM&M, including details of the technology and its possible applications. Each technology's advantages, challenges, limitations and risks were also discussed.

MATERIALS IN 2040

Advanced Metals and Composites

Driven by the desire to continually seek lighter, stronger and more durable structures, new metals and alloys will be used in both Defence and non-Defence settings. Cheaper and lower energy production and manufacturing techniques will see increased use of specialised materials such as titanium and carbon fibre in many applications. Other specialised materials such as amorphous metals and superalloys will provide new opportunities with special magnetic properties and high-temperature resistance.

Progression in materials science will allow for extremely strong and durable products or components to be developed, as well as highly efficient sensors and conductors. The ability to produce metals with specific degradation quantities and deformation characteristics will also enable novel applications in aerospace and biotechnology that were previously considered unfeasible.

Nanomaterials

Nanomaterials are loosely defined as materials having a single unit sized less than 100 nanometres in at least one dimension. They have a large relative surface area, which leads them to be far more reactive in smaller sizes than the same material in larger particles.

While many potential applications are possible, the use of nanomaterials in semiconductors, sensors and filtration may take a long time to develop. There are some current applications of graphene sheets and nanotubes in ballistic armour, and their high strength and ability to withstand high temperatures could see many future applications in protection, armour and radiation shielding. Increasing applications of graphene will also depend on development of a more rapid production technique in order to produce more economic quantities of material.

Energy Storage and Energetic Materials

Energetic materials are typically classed as explosives, propellants and fuels. Future developments in explosives, such as nano-thermites and super-thermites, may open up new opportunities in explosives ordnance and missile systems. These materials combine reactive materials at the nanoscale, and will increase both energy storage and the rate of energy release compared to traditional applications of reactive materials. Developments in biofuels, including the production of dimethyl ether (DME) from biomass, may make it feasible to produce fuel for vehicles in a variety of contexts more efficiently.

Development in higher energy density batteries, such as Li-Air, will create a much higher energy storage capacity than is currently available. Coupled with advances in energy management systems, new battery technology will enable increasingly complex and long-lasting wearable technology.

The use of polymers in energy generation and storage could also emerge due to their conductivity and light weight. Polymers can be nano-engineered and structured for unique applications, opening up a range of potential new applications in renewable and portable energy.

Specific Property and Smart Materials

The rapid progression of materials modelling and research could produce materials with properties that are not naturally available. While the possibilities in this field in 2040 are wide-ranging, the development of self-healing materials and metamaterials in particular could produce properties with many applications.

Certain fibre-reinforced polymers and other materials will be able to react to scratches, cracks and dents caused by defects, stresses and impacts. These materials will have agents inbuilt into the material to react to changes in the structure and repair damage. Alternatively, their repair mechanisms can be activated by heating or by exposure to oxygen. Self-healing materials will have applications in aerospace and a range of vessels that traditionally require regular inspection and the maintenance of damaged components.

Metamaterials – materials manufactured to have properties not found in nature – will be used in many applications. In particular, metamaterials that have a negative refractive index could be used to create new varieties of camouflage or stealth equipment and suppressing sound. They could also improve communications and surveillance with highly precise antennae and optical lenses, and could have signals sent and received by structural components of planes or vehicles rather than antennae.

Biomaterials

A biomaterial is any substance that has been engineered to interact with biological systems for a medical purpose – either a therapeutic or a diagnostic one. Synthetic biology and tissue engineering are key growth areas in the biomaterials field, employing techniques from computer science, biology and engineering to create new materials not only for medical use but for a wide range of other applications. Currently, biomaterials such as synthetic compounds and composites are used as aids or substitutes for bones within the body.

Over the next 30 years, it is possible that synthetic biology will give rise to engineered entities that can create biofuels from industrial waste, deliver therapeutic medicines for cancer treatment and detect and remove environmental contaminants to provide for cleaner air and water.

A key convergence of technologies is occurring in tissue engineering with the use of 3D printing techniques for the fabrication of living tissue, a technique known as bio-printing. Although making whole organs is not yet feasible, the first clinical applications have already emerged in printing models of patients' heart valves, blood vessels, or other organs for the treatment of vascular disease.

Computational Modelling of Materials

Producing materials with specific properties for application will be underpinned by powerful theoretical and predictive modelling. Computational techniques across the scales of the atomic through molecular, nano- and macro-scale will be able to facilitate the discovery and design of new materials at a much greater pace than is currently available.

In conjunction with advancements in machine learning and artificial intelligence, the rate at which new materials and material combinations can be discovered and studied will greatly increase.

MANUFACTURING IN 2040

Additive Manufacturing

Stakeholders identified advances in manufacturing to be driven primarily by the increased prevalence of additive manufacturing and its variants. Additive manufacturing is an alternative to the traditional product manufacturing process where objects are produced by cutting and forcibly shaping raw material and constructing an object through the use of moulds and dyes. Additive manufacturing builds up a shape by successively building an object in layers, building more complex, customisable materials with very little waste of material.

The most common additive manufacturing techniques use 3-D printing in layers. First, it takes graphical data input from the computer, which is often created using a computer-aided manufacturing tool, and cuts the data to serve as separate object layers or components. The segmented/layered graphical data is sent to a 3-D printer or similar production unit, which applies the required combination of raw material for that particular layer. The printer then adds up the product development layer by layer until it is completely designed and finished according to the design criteria.

3-D printing has the ability to fundamentally change the way we manufacture everyday items. Although 3-D printers are not new, their application and variants are likely to progress much further. Current versions of 3-D printers are capable of printing material as small as 2.5mm, while larger scale printers can produce one1 tonne per day. This type of manufacturing with such a high level of precision and rate could theoretically be extended to large scale production to entire tanks and submarine skins.

The material properties of additively manufactured products in the future could be highly precise and individually customised. The emergence of techniques such as cold spray application could see the rapid production of high strength metal structures be rapidly produced in shapes that are not currently possible, and lead to vast savings in materials used. Cold spray technology could also allow many new materials to be used and allow additive manufacturing to occur in new environments (Figure 1Error! Reference source not found.).

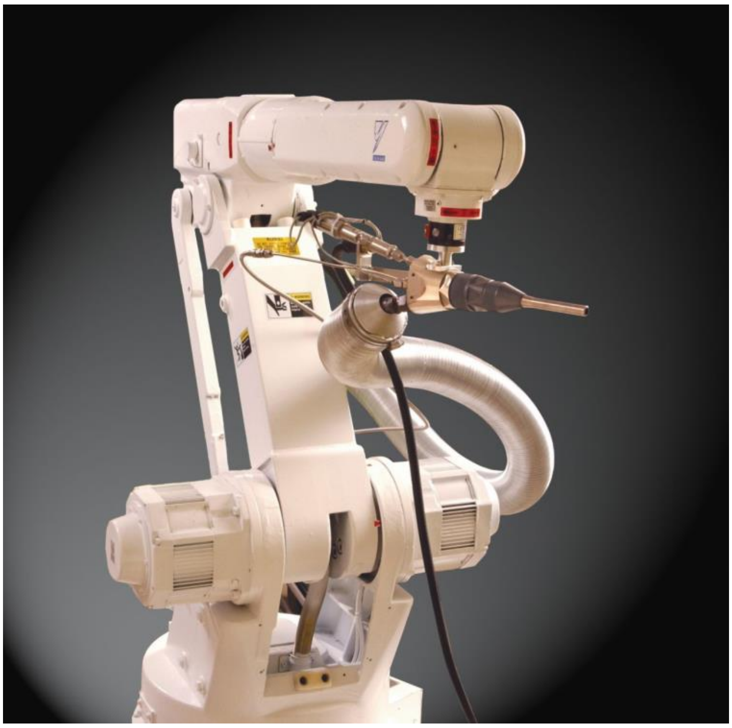

Figure 1. Spray nozzle on a robotic arm for complex additive deposition at Lab 22 (Copyright CSIRO, 2016).

Hybrid Manufacturing

Hybrid manufacturing is the combination of laser cladding and computer numerical control milling within a single machine environment. Hybrid manufacturing produces objects by employing both additive and more traditional subtractive technologies. Because of its dual nature, hybrid machines can begin producing a part by using either an additive or subtractive process. However, beginning production using additive manufacturing is inherently more efficient than needing to mill a form and, in most cases, will offer greater design freedom. As pointed out by stakeholders, hybrid manufacturing will become a more common process for the Defence industry and everyday use.

Printed Flexible and Embedded Electronics

Flexible electronics have the potential to save space and provide more computing power to non-flat areas, while additive manufacturing techniques allow circuits and complex electronics to be built into the structure of components. By using flexible and embedded electronics, sensors, communications and computing devices could be built into submarines, tanks and planes in ways that minimise weight, save space and utilise space that is traditionally difficult to use. Flexible electric circuits could also increase circuit density and eliminate bulky wiring and connectors, enabling new technologies to flourish in fields such as wearable electronics, solar power generation and energy storage.

Industry 4.0

Digitisation, automation and machine learning are considered by some stakeholders to drive the "fourth industrial revolution" (Figure 2). The introduction of artificial intelligence, cloud computing and big data analytics will enable more efficient and agile manufacturing than ever before. In combination with increasingly powerful additive manufacturing technologies, the process of designing, building and testing products will be made cheaper, faster and more flexible. Predictive modelling will aid sound design, while 3-D printers will be able to quickly produce prototypes of these designs for the iterative development of new technologies and products. These advances will be accessible at the smallest scale, allowing small footprint 'microfactories' to produce highly specialised products almost anywhere. Alternatively, manufacturing can be provided as a service business, where researchers and designers can send their products to manufacturing providers electronically to be produced on a large scale.

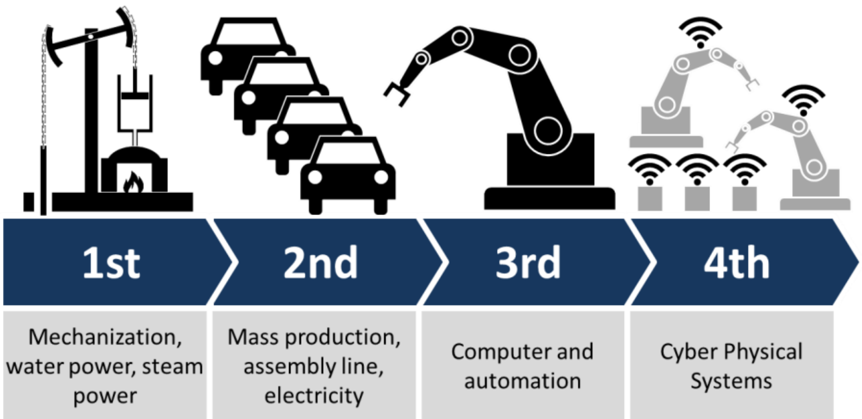

Figure 2. The four "Industrial Revolutions" defined by the German Industry-Science Research Alliance (Source: Christoph Roser at AllAboutLean.com).

The Maker Movement and Extreme Manufacturing

Industry 4.0's range of new technologies, increased availability of design tools and data, and low barriers of entry to the fabrication and manufacturing fields has led to the emergence of the "Maker Movement". Combining and altering existing products and making use of readily available platforms has allowed sole traders and small businesses to build and market innovative products, using crowdfunding to find highly niche consumer markets and quickly bring new technology to market. In 2040, the Maker Movement could see highly profitable products being developed and marketed from backyards, garden sheds or city office blocks.

The combination of computer-driven design and manufacturing as well as faster manufacturing techniques has led to product development approaches from the software industry being applied to manufactured goods. "eXtreme Manufacturing" is the most advanced of these methods, combining Scrum software development methodology and other software programming frameworks with lean manufacturing principles to rapidly design, build, test and iterate new products and technologies (Figure 3. Components of eXtreme Manufacturing (Adapted from Scrum Inc.)

This more rapid and more atomised industrial landscape will see much quicker development and marketing of products, as well as a proliferation of customised, modularised and ever-changing manufacturing systems.

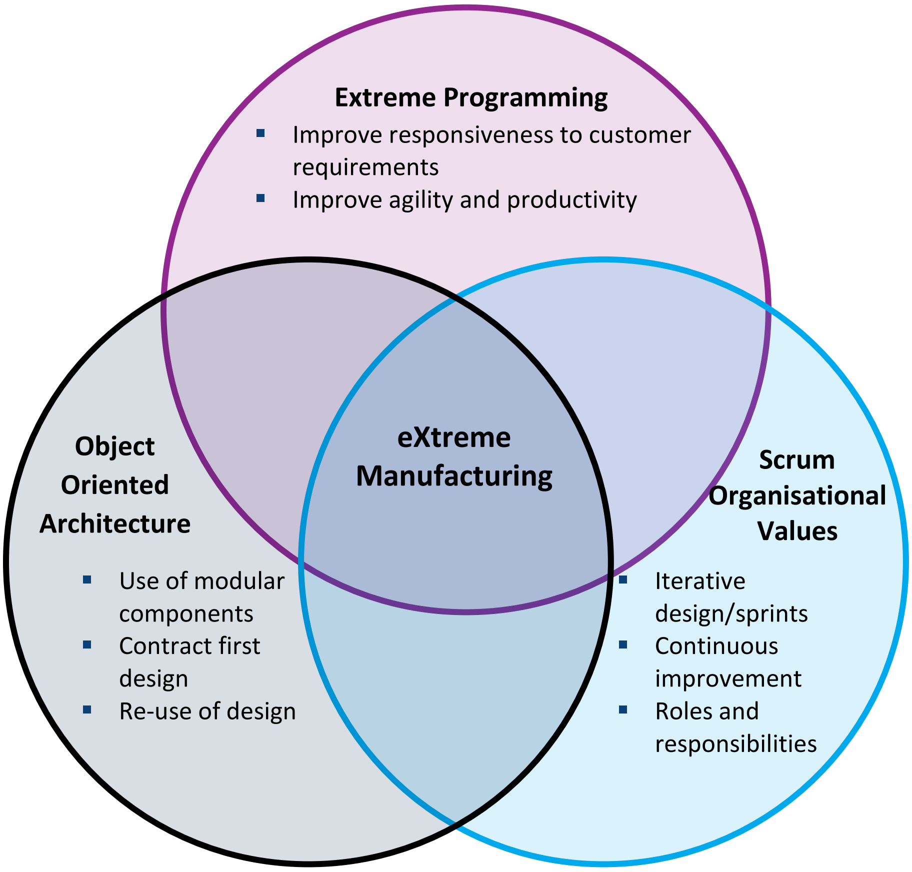

Figure 3. Components of eXtreme Manufacturing (Adapted from Scrum Inc.).

AUSTRALIA'S FUTURE INDUSTRIES

Since the 1960s, manufacturing and the production of goods in Australia has stagnated and declined. Between 2008 and 2015 alone, employment in manufacturing has declined by 18%, representing approximately 190,000 jobs. This number represents a broader loss of industries related to producing goods in Australia, with the economy becoming increasingly dominated by the services sector as well as construction and primary industries. The key findings for the AM&M EDTAS concern the sovereign capabilities in Australia, particularly for Defence and its related industries. The insights also consider how developments in materials and manufacturing will lead to more uncertainty and rapid change in the industrial landscape.

The prevailing view among stakeholders is that by 2040, manufacturing will likely form part of a more vertically-integrated economy where the design and development of low volume, high value goods will replace the large scale, high volume manufacturing model seen in many sectors.

The rapid reduction in the size and scope of Australia's manufacturing base is unlikely to be quickly reversed. However, Australia has significant opportunities for growth in selected areas as manufacturing technology progresses. The wide availability of additive manufacturing technologies and digitally integrated supply chains will see two major developments that shape Australia's industrial landscape:

- **Manufacturing as a service**. Companies designing and developing new products or technologies will be able to send their designs to nearby or overseas manufacturers who can convert their designs into products rapidly and accurately. 3-D printing and common design platforms will make it simpler than ever to prototype and produce products. Furthermore, many customers may only require designs and material specifications to be provided, producing the product they require at their location with their own manufacturing assets.
- **Increased vertical integration**. Specialised manufacturers, especially those that produce low volume, high value goods, will be able to have complete control of the value chain in their industry. The barriers into manufacturing will be lower and the range of goods able to be produced will be greater than it is now. Agile techniques to product development will enable companies to rapidly design, build and test their ideas and produce their products iteratively all in the same geographic location or within the one company.

These developments will have positive implications for many Australian companies and will favour small, niche technology and manufacturing companies. Companies will be less burdened by the cost of geographical barriers due to a reduction in:

- freight requirements
- time taken to commercialise products
- capital required for factories and manufacturing infrastructure.

As a result, the value drivers for Australian manufacturing companies will be in research and development (R&D), ideation and product design of goods. At the same time, Australia's services sector will experience increased automation of processes in areas such as legal services, finance and accounting. Both of these factors will see the emergence of an economy based on a high level of specialisation and subject matter expertise.

While the Maker Movement and manufacturing as a service will allow small companies to make new products at a low cost, many parts of the manufacturing sector will still be dominated by those companies who can pursue large economies of scale in key areas. In particular, converting new technology into mass market products will still be a major value driver. For instance, Tesla's planned "Gigafactory" seeks to reduce the cost of lithium battery production by 30% by creating a vertically integrated, high volume factory to service their own product lines. This model will be replicated by similarly large, well-capitalised organisations for a variety of mass market products. Given the type of capital investment required for these projects, large international, vertically integrated technology companies will dominate in the development and production of high technology goods. It is unlikely that Australia will be able to host or produce comparable companies.

Australia's areas of expertise could include products requiring premium or highly advanced materials, such as advanced composites, titanium alloys and new polymers. The industries that will drive demand for these parts are:

- biotechnology products such as body parts and joints
- aerospace, automotive and niche industrial applications
- 'smart' infrastructure such as public transport and renewable energy.

Defence Industries in 2040

Stakeholder observations suggest that the Australian Defence Force will still require significant domestic support, in order to sustain its capabilities and key platforms. This support will come from a mix of Australian companies, the onshore presence of major international companies and from within Defence itself.

Defence in 2040 will require a host of new material in use or in development. The adoption of tougher, more durable and more lightweight materials will drive Defence capabilities, while new methods of production and manufacturing will increase the application of materials such as carbon fibre and titanium. Additive and hybrid manufacturing will allow these materials to be produced with embedded computing, sensors and communications to create compact and high-powered components in fields such as avionics. These advanced manufacturing components will also be increasingly more cost-effective, as they use materials far more efficiently and allow the creation of optimised structures that are otherwise not possible to fabricate. In the context of large structures such as submarines, far more efficient manufacture and design of simple but ubiquitous components such as pipe hangings can have significant effects on weight and energy requirements.

The use of carbon fibre will be extended to applications such as damping in marine vessels, while larger scale graphene production could see its application extend to small, wearable technologies as well as armouring and radiation protection.

Capabilities involving sensing and detecting will also be enhanced with the rapid development of functionally-specific materials. Coatings of metamaterials may be able to provide new levels of multi-spectral stealth and camouflage, while adaptive and purpose-designed materials will enable vehicles to function in variable or extreme conditions including in space and suborbital flight.

Advanced energy storage and more efficient conductors will allow a host of wearable technologies to be used by personnel. Coupled with advances in biotechnology, soldiers in 2040 will have significant health information available to them and enhanced ability to process information and communicate in the theatre of war. Clothing will also be multifunctional and may have the ability to collect water or energy when in the field.

With the rapid development of these technologies, Defence platforms, such as future submarines and the Joint Strike Fighter, could be upgraded by the improvement of materials and component. Sustainment of these platforms and essential maintenance may also be improved by new manufacturing technologies, allowing components to be produced on-site where they are required. Maintenance of Defence capabilities will also be made faster and cheaper by the introduction of self-healing materials and laser repair of structures. These technologies will make non-routine maintenance less common and greatly reduce the need to replace components.

The emergence of advanced materials and rapid manufacturing could have a significant impact on not only Defence capabilities, but also the logistics and support of operations. Supply lines can be reduced and simplified by the adoption of on-site manufacturing and build processes, requiring only the transport of raw materials in support of operations. Additive manufacturing will not only allow much lighter structures to be used in applications such as naval vessels, it will also reduce the amount of space required for transport by simplifying the type of equipment and materials to be transported. For instance, moving sheets of material or powdered metals requires less space and presents an opportunity for a more streamlined supply chain than transporting complex components or already assembled assets.

To enable these developments in advanced materials and manufacturing, Defence will attain a greater level of cooperation and engagement with suppliers and R&D activities. This will not only include highly specialised Defence areas, but also make use of commercial technology produced for mass market products such as the iPhone.

Defence platforms will be able to continually adapt and improve. The capability acquisition process in 2040 could see considerably less buying “off the shelf”; instead moving to adaptable, modularised platforms which allow many companies to influence capability and provide highly specialised, cutting edge technology.

Increasingly autonomous systems and artificial intelligence may also see the emergence of a more “disposable” approach to capabilities. Unmanned vehicles may be quickly developed and recycled into newer versions with far less testing and quality assurance. Traditionally, platforms could be supported by more ambitious new ventures, where the time from design stage to deployment is squeezed to a minimum in order to create new capabilities and react quickly to emerging threats.

Although new materials and manufacturing technology could see a variety of capabilities flourish, Australia will still work closely with partner nations and seek interoperability with their capabilities. Relationships between forces will be critical to the quick development and acquisition of new capabilities, with Australia able to benefit from the R&D of its partners more quickly.

IMPLICATIONS

From our interviews, several implications of advances in materials and manufacturing techniques were identified. These represent significant changes to be embraced, barriers for Australia and Defence to overcome and potential risks posed in 2040 by these advances.

Pace of Change

Researchers have labelled new manufacturing techniques, along with increased automation, artificial intelligence and computing power as the "fourth industrial revolution". The structural changes to industries, the economy and society could increase rapidly, and major upheaval to the employment markets, regulatory regimes and the competitive business environment.

We currently have a narrow understanding of the potential applications of developments in advanced materials and manufacturing, with many more applications to emerge and potentially disrupt existing business models and usurp current technologies. Many Australian businesses may be reluctant to embrace emerging technology, and this could see Australia fall behind in many sectors. The reduced barriers to entry into manufacturing and the potential for rapid design and build may also present opportunities for entrepreneurial companies and start-ups that emerge from applied research breakthroughs.

Australia is viewed as a relatively conservative society, slow to take up business innovations and with an overemphasis on primary industries. Australia will also need to embrace higher education to a greater extent in the manufacturing sector, encouraging further study in technical areas and incorporating the latest materials and manufacturing into the education of new mechanical, software and chemical engineers.

> Can Australia's government, businesses and workers embrace the changing industrial environment, or will we fall behind?

For the Defence Force and Defence sector, this rapid change in materials and manufacturing may see certain capabilities become obsolete very quickly. For example, stealth capabilities and sensors designed for future platforms may be ineffective by the time they are in service. Australia will therefore need to maintain some agility in order to improve existing capabilities or quickly produce new capabilities in response to more rapidly changing technology. Defence capability acquisition is also heavily wedded to platforms, and this may not be sufficient to meet future capability challenges. These platforms must be more easily adapted or even more quickly replaced in order to accommodate rapid advances in technology.

> How do we increase the pace at which new materials and manufacturing technology are identified and adopted in Defence capabilities?

Assurance

One of the key advantages of advanced manufacturing will be the production of bespoke or low volume items with a significantly reduced cost. This will increase the reliance on modelling and simulation to verify and validate products and components. Traditional quality assurance and certification processes rely on and purpose-built and tested production lines, which will not be viable in an environment of rapid, agile 'design and build' manufacturing techniques.

The safety and reliability of new materials and manufactured parts will depend primarily on the design process. Design processes will be informed by big data analytics as well as developments in artificial intelligence. Modelling and analysis of design strength will need to predict fatigue properties, define key parameters and give a level of assurance in the built product's quality.

The use of design standards will change considerably, requiring the creation of a relevant ontology and large materials and manufacturing databases. There is currently a lack of empirical data to inform standards for new techniques such as additive manufacturing, meaning that early adopters of this technology will need to take on risk or additional cost to test products.

How will trust and assurance be maintained with a proliferation of new materials and manufactured products?

Will we be prepared to accept new manufactured products without rigorous testing and validation in order to more rapidly progress technology?

For Defence and related industries, testing and verification is critical due to the high personal safety consequences of errors and improper design. Where there are not people involved, such as on autonomous platforms or vehicles, the prospect of adopting a more agile approach to designing and testing new products is slightly more feasible.

Where can agile manufacturing and rapid design and build approaches be applied in Defence capability? Can testing and verification be streamlined to facilitate advances in materials and manufacturing?

Material Resources

More advanced materials are typically expensive to use, and often require the input of other materials that are difficult to source. In terms of Defence, the increasing demand for lighter, stronger structures means that titanium will be in demand for more and more applications.

While the supply of raw materials such as titanium minerals is critical to securing required resources, it is not the primary consideration. For instance, Australia has considerable resources of titanium minerals and is a world leader in the production of titanium minerals. However, the production of titanium metal from its ores is highly complex and wasteful, meaning that it is currently unviable for Australia to produce titanium metal as opposed to titanium mineral products such as rutile. If there is a major increase in demand for titanium metal in the future, this may change.

Can Australia’s own natural resources lead to a strategic advantage in the development of advanced materials and manufacturing?

There are also some raw materials which present a strategic challenge. Rare earth elements are increasingly required materials in many new technologies, but the global supply is dominated by Chinese producers. Any changes to trade relationships could therefore have large consequences for the production of electronics and Defence-related products.

What strategic risks do we face from reliance on expensive, rare or imported resources in advanced materials and manufacturing?

The Manufacturing Value Chain

In an increasingly globalised value chain from R&D through to sales and marketing of products, Australia has typically not had the ability to compete in all aspects of the chain. In particular, Australia has lacked the ability to produce and distribute mass produced products due to its geographical isolation, small domestic market and relatively high cost environment. However, with the development of high value materials and the availability of manufacturing as a service, the importance of manufacturing to the value chain will be minimised in comparison to R&D, design and sales, exaggerating a trend observed since the 1970s (Figure 4).

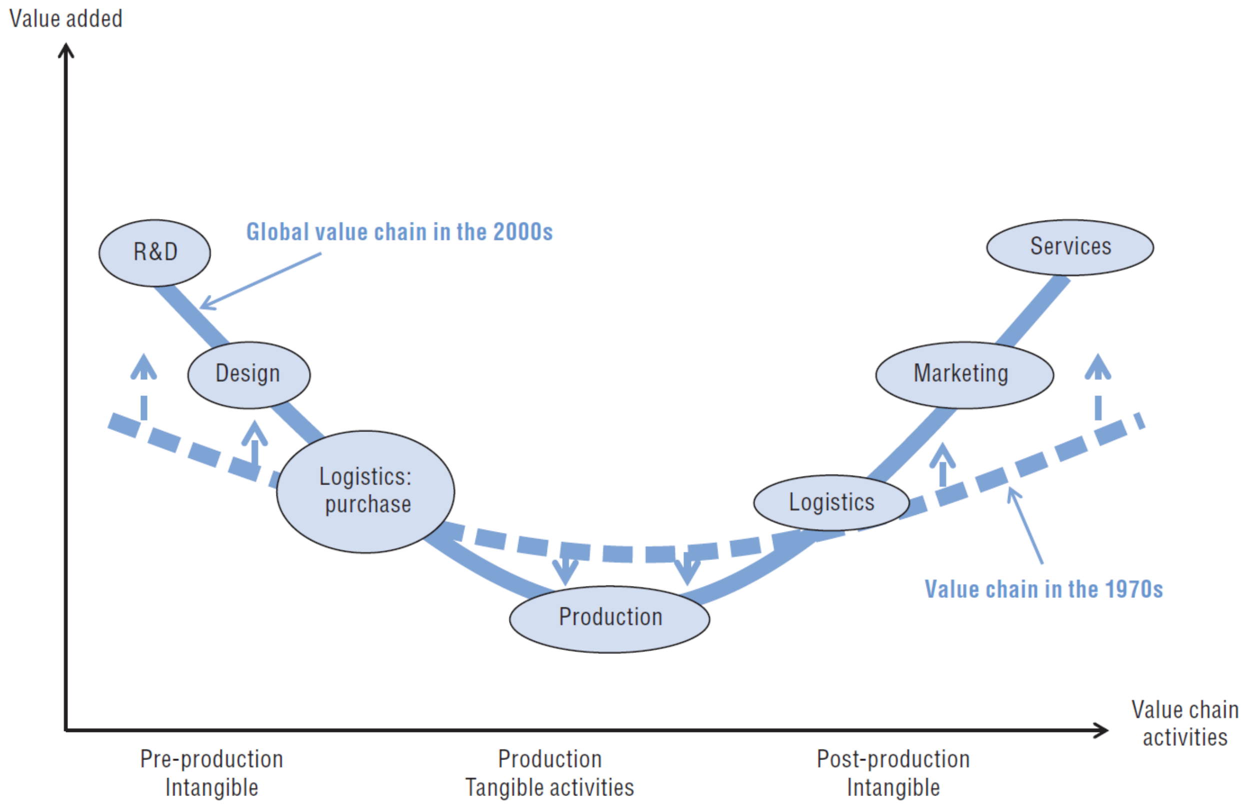

Figure 4. Changes in value distribution along the global value chain from 1970s to now (Source: "Interconnected Economies Benefitting from Global Value Chains", OECD 2013).

Australia will need to focus on complementing its significant service sector with a growth in the design and sale of high value goods. It will also need to foster R&D in academic institutions, research institutions and in businesses. Research will need to be intertwined with industry, with significant investment in the commercialisation of new materials and manufacturing techniques.

In Defence-related industries, advances in materials and manufacturing may provide an opportunity for Australian small to medium-sized enterprises (SMEs) to become part of the global supply chain for major defence platforms such as the Joint Strike Fighter.

How can Australia foster high value industries and capture a greater share of the manufacturing value chain?

National Security

With the emergence of Industry 4.0 and the digitisation of the manufacturing landscape, the threat of 'hacking' or other cyber-attacks will rise and will come with a higher potential cost to organisations. In particular, the theft of intellectual property will become more commonplace and will require significant attention.

The ability to download designs and manufacture a wide variety of complex products also presents wider security challenges. If weapons could be produced by additive manufacturing, the task of controlling arms coming into a country becomes nearly impossible. The ability for terrorists or other actors to access new technologies and present ever changing threats may pose significant national security challenges and further complicate asymmetrical warfare scenarios.

How does Australia deal with the new and continually changing threats posed by advances in materials and manufacturing?

Domestic Capabilities

While the ability to execute our own complex, large scale defence acquisition projects represents a significant strategic advantage for Australia, it would come at a premium cost due to Australia's small scale and limited resources. Advanced materials and manufacturing represents an avenue for Australia to reduce the cost associated with domestic projects by allowing for a range of highly specialised components to be produced in the country.

Australia has the potential to produce strong management and a highly skilled workforce. This will only be possible if the "clustering" of key education, research and commercial activities can be achieved on a significant scale. Silicon Valley and Tel Aviv and are examples of how centres of innovation and high value industries can become self-sustaining and produce significant outcomes for Defence-related industries.

Australia's ability to produce certain key materials would also enable significant manufacturing growth. As an example, the construction of a carbon fibre production facility and native production of titanium metal would service industries providing high value products in the Defence sector and other niche applications.

How can Australia maximise its domestic capabilities in Defence-related industries?

R&D Process and Collaboration

Australia's manufacturing sector includes many SMEs that lack the ability to drive research and to attract significant investment in commercialising technology. For these SMEs to take advantage of advanced materials and manufacturing in the future, Australia will require greater collaboration between academia, research institutions, businesses and the Government to drive research and enable commercialisation of new technology.

In Defence-related applications, more collaboration between organisations will help to both improve co-operative programs, such as the Joint Strike Fighter and next generation submarines, and provide opportunities for domestic industries in this sector. Collaborate could also mean longer term embedding of staff in different organisations to share knowledge and to enable each organisation to fully understand each other's capabilities.

Progress in R&D will require a unified picture of what research is currently underway in Australia and what the broader needs and priorities are for Defence. Clarity on what Defence needs will enable it to influence research undertaken and potentially realise the capabilities it seeks through Australian R&D.

How can collaboration between Defence, research bodies and Industry best enable new technologies in advanced manufacturing and materials?

CONCLUSION

The stakeholders interviewed in preparation for this Insights Paper provided a range of perspectives on advanced materials and manufacturing to create these insights. They also included significantly more detailed insights in their specific areas of expertise that could not be justly represented in this paper.

Most stakeholders concurred that the predicted changes due to advanced materials and manufacturing represent an opportunity for Australia's economy and its Defence capabilities, although there are many barriers that must be overcome in order to realise these opportunities. In research and in Defence, the need to understand the nature of these barriers, and how to best overcome them, was continually emphasised. The AM&M Symposium will explore these barriers in addition to the vast potential applications of advanced material and manufacturing.

ANNEX A: STAKEHOLDER INTERVIEWS

Prof Russell Varley	Carbon Nexus / Deakin University
Dr Cathy Foley	Deputy and Science Director of Manufacturing, CSIRO
Dr Keith McLean	Director of Manufacturing, CSIRO
Prof Ying (Ian) Chen	Nanotechnology Chair, The Australian Future Fibres Research and Innovation Centre, Deakin University
Dr Mark Hodge	CEO, Defence Materials Technology Centre
Dist. Prof Suresh Bhargava	Director, Centre for Advanced Materials and Industrial Chemistry, RMIT
Prof Milan Brandt	Director, Centre for Additive Manufacturing, RMIT
Dist. Prof Shi Xue Dou	Director, Institute for Superconducting and Electronic Materials, University of Wollongong
Dr John Knott	Fellow, Institute for Superconducting and Electronic Materials, University of Wollongong
Jeff Lang	Director of Technology, Titomic
Prof Emily Hilder	Director, Future Industries Institute, University of South Australia
Mr Neil Matthews	VP Research and Technology, RUAG Australia
Prof Kamran Ghorbani	Research Director, Communication Technologies Research Centre, RMIT
Dr R.E. Burnett	College of International Security Affairs, National Defense College
MAJGEN Kathryn Toohey	Head of Land Capability
AIRCDRE Mark Green	Director General, Strategy and Planning, RAAF
AVM Catherine Roberts	Head, Aerospace Systems Division, CASG
RADR Greg Sammut	Head, Future Submarines Project
BRIG Michael Mahy	Director General, Military Strategy, Department of Defence