Recycling and Clean Energy
National Manufacturing Priority road map

Our Vision
To develop world-leading advanced manufacturers that seize opportunities from sustainability, clean energy transition, and waste reduction demands by leveraging Australia’s advantages in innovation, technology, renewable and mineral resources, and our onshore industrial base.

Our growth opportunities

<table>
<thead>
<tr>
<th>Manufactured products that enable recycling or use recycled feedstock</th>
<th>Manufactured products that enable or use clean energy</th>
<th>Overlapping manufacturing opportunities</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Recyclable products and packaging</td>
<td>• Hydrogen tech, high-voltage direct current (HVDC) cabling, thermal energy and modularised renewables (and other components for large industrial systems)</td>
<td></td>
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<tr>
<td>• Cleaner feedstocks for remanufacturing (and enabling tech)</td>
<td>• Microgrids, inverters, electric vehicle chargers and next generation photovoltaic (PV) modules (and other enabling tech for distributed energy)</td>
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<tr>
<td>• Products from recycled feedstocks (such as plastic, organic waste or e-waste)</td>
<td>• Specialised batteries, grid-scale batteries and battery precursors (moving up the value chain, from mining to making)</td>
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<td></td>
<td>• Low emissions steel and aluminium (and other energy-intensive manufacturing with clean energy and carbon capture, use and storage (CCUS))</td>
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<tr>
<td></td>
<td>• Carbon fibre and graphene (and other advanced materials)</td>
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<tr>
<td></td>
<td>• Recycling clean energy components (including PV panels, wind turbines and batteries)</td>
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New technologies and products will be technically and commercially proven, and more businesses will be ready to take advantage of accelerating trends favouring sustainable production.

2 YEARS
Find, design, develop and make product solutions needed for sustainable energy and material systems

5 YEARS
Businesses building on capabilities and products, with continued investment in market-leading innovations and increasing scale. Maturing markets for green technologies and products will be helping to pull this through.

10 YEARS
Growth in Australian R&D, design, production, sales and services will cement our position as a leading manufacturer of solutions to help Australia and the world transition to more sustainable energy and material systems.

Unlocking our opportunities—the first two years

**FOCUS**: Developing world-leading products that take advantage of growing demand for clean green products, supporting domestic manufacturers to benefit from industry growth, and mobilising large-scale manufacturing investment in new ways of using energy and materials.

<table>
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<th>Develop world-leading greentech products</th>
<th>Supporting domestic manufacturers to benefit from growth</th>
<th>Mobilise large scale investment in new ways of using energy and materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Find, design, develop and make product solutions needed for sustainable energy and material systems</td>
<td>Tap into manufacturing opportunities flowing from large energy projects and changing consumer preferences</td>
<td>Consortiums across supply chain tackling barriers together</td>
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1. The Modern Manufacturing Strategy

The Australian Government is manufacturing a new future for our nation. Manufacturing is critical to a modern Australian economy—a key part of almost every supply chain that adds significant value to all sectors. The Modern Manufacturing Strategy (MMS) is led by industry, for industry, to help our manufacturers scale-up, become more competitive and build more resilient supply chains. The Australian Government will be a strategic investor in this, notably through the 6 national manufacturing priority sectors. Prioritising these sectors will drive productivity and create jobs for Australians, both now and for generations to come.

On 1 October 2020, the Australian Government announced a $1.5 billion investment in the MMS to help Australian manufacturers become more competitive, resilient and build scale in the global market. The 6 key areas of focus are:

- Resources Technology & Critical Minerals Processing
- Food & Beverage
- Medical Products
- Recycling & Clean Energy
- Defence
- Space

Through the MMS, the Government wants to support projects from industry that will transform manufacturing in Australia. The Recycling & Clean Energy road map will help inform investment decisions that both Government and industry make over the next 10 years to support projects that will:

- develop world-leading product solutions that offer clear value to growing green markets
- support domestic manufacturers to benefit from opportunities created by large energy projects and changing consumer expectations
- mobilise large-scale investment in new ways of using energy and materials, by bringing together collaborations across supply chains to tackle barriers together.

Co-investment is critical for each step of this solution pathway. It will complement a broader policy environment supportive of manufacturers in both recycling and clean energy.

The MMS outlines the whole-of-government agenda to help grow Australian manufacturing and ensure our manufacturers can harness global opportunities and achieve scale and competitiveness. It is built on four pillars (see Figure 1).
Figure 1: 4 pillars of Australia’s Modern Manufacturing Strategy

Australia’s Modern Manufacturing Strategy

<table>
<thead>
<tr>
<th>GETTING THE ECONOMIC CONDITIONS RIGHT FOR BUSINESS</th>
<th>MAKING SCIENCE AND TECHNOLOGY WORK FOR INDUSTRY</th>
<th>FOCUSING ON AREAS OF Advantage</th>
<th>BUILDING NATIONAL RESILIENCE FOR A STRONGER ECONOMY</th>
</tr>
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<tbody>
<tr>
<td>• Helping restore business confidence and recovery through the JobMaker plan</td>
<td>• Aligning research and innovation capabilities and programs to priority areas</td>
<td>• Setting National Manufacturing Priorities and developing road maps for action</td>
<td>• Making supply chains more resilient to external shocks including through a Supply Chain Resilience Initiative</td>
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<tr>
<td>• Delivering lower energy costs</td>
<td>• Unlocking investment proposals through the Manufacturing Modernisation Fund round two</td>
<td>• Backing projects with wide reaching impacts through the Modern Manufacturing Initiative</td>
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</tr>
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<td>• Building management capability</td>
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<td>• Getting our tax settings right</td>
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<td>• Tackling red tape</td>
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<td>• Improve our industrial relations system</td>
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Getting the economic conditions right

Getting the economic conditions right is the first pillar of the Strategy, noting affordable and reliable energy, lower taxes, industrial relations, training and skills, and cutting red tape are key determinants of success for our manufacturing businesses.

The Australian Government is working hard on getting the economic conditions right for manufacturers, paving the way for growth and improved competitiveness in all sectors.

The Government is focused on making and sustaining jobs through the JobMaker scheme. Temporary full expensing and temporary loss carry back measures will unlock investment and expand the productive capacity of the nation.

Manufacturers need a pipeline of skilled workers as they transform and scale. The Government is investing $7 billion this financial year to keep apprentices in jobs, to help jobseekers re-skill and to promote vocational training. We are working to ensure that we are creating the jobs of the future and that we have a pipeline of skilled workers to support new and emerging industries, including in the recycling and clean energy manufacturing sector. The Government’s reforms to higher education will boost the number of graduates in areas of employment growth—including STEM.

The National Waste Policy aims to reduce waste where possible and make productive use of waste where it is generated. The National Waste Policy Action Plan, Recycling and Waste Reduction Act 2020, and National Product Stewardship Investment Fund will increase material recovery rates, ban the export of key waste streams, support product stewardship initiatives, and boost the role of government as a procurer of recovered materials.

A gas-fired recovery will ensure Australian gas is working for our businesses and manufacturers, with a 13-point plan and supporting investments to unlock supply! This complements the Government’s initiatives to reduce electricity prices, boost liquid fuel security and invest in low emissions energy technology through the Technology Investment Roadmap. Australia’s Future Fuels Strategy will enable consumer choice and support the uptake of new vehicle and fuel technologies.

This roadmap will assist manufacturers to bring recycling and clean energy products to market, complementing these initiatives and delivering economic value and jobs for Australia (see Figure 2).

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1 Minister Pitt (2020) Minister welcomes Narrabri approval
Focusing on areas of advantage

The third pillar of the Strategy is to set National Manufacturing Priorities, develop road maps for action, and back projects through the Modern Manufacturing Initiative (MMI) which support the transformation of manufacturing in these sectors. Road maps are being developed with industry to set out plans for both industry and Government to strengthen Australia’s manufacturing capability. The road maps have been led by industry taskforces to identify and set a future vision for priority areas with clear goals, opportunities and actions over the next 2, 5 and 10 years.

The road maps are designed to be dynamic. As the MMS is implemented, we will continue to work with industry to ensure the road map evolves over its life. This will take account of emerging opportunities and actions to support the sector to scale-up, become increasingly competitive and for businesses to integrate their commercial solutions with global supply chains and markets. See Appendix A for more details on the road map process.

The MMI aims to support manufacturers to more quickly bring their products to market and invest to scale their manufacturing operations in Australia. The road map will support industry to overcome late-stage commercialisation barriers and help government identify high impact projects. The role of the MMI complements other government programs to support the development of the recycling and clean energy sector (see Figure 3).
Figure 3a: Modern Manufacturing Initiative in context: Recycling

<table>
<thead>
<tr>
<th>Pre-production</th>
<th>Production</th>
<th>Post-production</th>
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</thead>
<tbody>
<tr>
<td>R&amp;D</td>
<td>Design</td>
<td>Sorting</td>
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<tr>
<td>Demonstration</td>
<td>Processing</td>
<td>Remanufacturing</td>
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<td>Design</td>
<td>Reuse</td>
<td>Market development</td>
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<tr>
<td>Sorting</td>
<td>Market</td>
<td>End-of-life services</td>
</tr>
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Modern Manufacturing Initiative (Collaboration, Translation and Integration stream grants)

- CSIRO
- Recycling Modernisation Fund (Commonwealth, state and territory grants)
- Australian Recycling Investment Fund (Debt or equity finance via CEFC)
- Product Stewardship Fund
- Universities and Australian Research Council (ARC)
- Cooperative Research Centres (CRC)

Figure 3b: Modern Manufacturing Initiative in context: Clean Energy (adapted from Mission Innovation)

Early R&D - Applied R&D - Market demonstration - Deployment and commercialisation - Market accumulation - Diffusion

- ARENA
- CSIRO
- Universities and ARC
- Clean Energy Innovation Fund
- CEFC
- Emissions Reduction Fund
- Renewable Energy Target

Other pillars of the Strategy

The Modern Manufacturing Strategy includes two other pillars which will also be important to focusing government investments to support the competitiveness and scale of Australian manufacturing.

Making science and technology work for industry

Australia’s science, research and innovation capabilities are critical enablers of transformation in manufacturing. There is an opportunity to improve the uptake of digital technology, processes and practices by manufacturers. These support business competitiveness and will have positive spill-overs across our economy.

This work will focus our industry, science and technology investments, including through the work of the CSIRO, to support our National Manufacturing Priorities. This will help our manufacturers supercharge their operations and harness emerging opportunities.

It will also complement Government actions to harness opportunities from emerging technologies, build business digital capability and grow the cyber security resilience of Australian business.

Building national resilience for a stronger economy

The Supply Chain Resilience Initiative will strengthen Australia’s ability to access critical necessities, part of positioning Australia to respond to future supply chain disruptions to make us stronger and more resilient. It will build on government and industry efforts to rapidly address critical supply issues revealed during supply chain disruptions due to COVID-19.
2. Why recycling and clean energy manufacturing?

Materials and energy are at the heart of manufacturing. Modernising how we use them is central to building an advanced manufacturing economy that realises more potential from our resources and supports our national resilience, economic recovery and environmental sustainability.

The move to more sustainable solutions for materials and energy is happening around the world. Companies committed to greener supply chains—including manufacturers and their customers—collectively wield over $5 trillion in combined purchasing power. Over 1,100 companies worldwide have now pledged to reduce emissions in line with the Paris Agreement, often by working with their manufacturing suppliers and manufacturing customers. These global demand megatrends are reshaping the landscape for manufacturing, accelerated by market and policy pressure to reduce emissions and waste, the scale of public and private green investment, and the falling cost of technology. Australian manufacturers are well positioned to use our unique industrial advantages—combining innovation, abundant clean energy, material resources, and onshore industrial base—to become competitive global players.

Global trends

Global markets are gradually transforming from a ‘throughput economy’ (relying on virgin inputs and generating waste) to a ‘circular economy’ (where materials are reduced, reused, recycled and remanufactured). Since July 2019, over $14 billion of public circular economy investment has been announced globally. Private investors are also showing interest in financing the circular economy and driving demand for sustainable manufacturing. Citi has announced a $250 billion fund to invest in environmentally beneficial activities, including recycling. Australia is part of this shift. Our Waste Export Ban and National Waste Policy are stimulating manufacturing solutions for major waste streams along with industry-led initiatives such as the National Packaging Targets, adopted by 75% of the packaging market.

In 2020, the world committed around $640 billion to clean energy technologies. This was a record amount, 9% higher than 2019 despite the economic disruption of the COVID-19 pandemic. Venture capital and private equity investments in renewables and storage rose by more than 50% as technology costs continued to fall. On a pure energy generation basis, wind and solar photovoltaic are now the cheapest new electricity source for countries representing around two-thirds of the world’s population, and almost three-quarters of the world’s GDP. These accelerating energy investment trends are opening new opportunities for manufacturers.

Australia is aligned with these energy trends. In 2019, we deployed renewable energy at 10 times the per capita global average and faster than any other G20 economy. The Commonwealth expects to invest $18 billion domestically in low emissions technologies over the decade to 2030. Prospective clean energy ‘megaprojects’ commencing operation later this decade would be among the largest energy projects ever built, and could provide significant opportunities for domestic manufacturing.

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2 Carbon Disclosure Project (n.d.) Supply Chain accessed 1 February 2021
3 Science Based Targets (n.d.) Companies Taking Action accessed 1 February 2021
4 BloombergNEF
5 Ibid
6 Australian Packaging Covenant Organisation (2020) Our Packaging Future
7 Ibid
8 Ibid
9 Ibid
10 Departmental calculation based on data from IRENA’s Renewable Energy Statistics 2020 report and World Bank population data
12 For example Asian Renewable Energy Hub and Sun Cable
The Australian advantage

Australia has the key elements to capture manufacturing opportunities that flow from these trends. We now need to bring it all together and make it happen.

We have barely begun to tap the abundant re-manufacturing potential of our waste streams, especially for plastics, glass and e-waste. Less than 5% of our plastic consumption is currently recycled. CSIRO estimates we could capture up to $3 billion value each year through lithium battery recycling alone.13

We have exceptional natural resources which offer significant green manufacturing potential. Our clean energy resources are unrivalled in the developed world.14 We are also a top producer of critical minerals, rare earths and important base metals that the global energy transition demands.15 Manufacturing batteries, electric vehicles, solar panels and wind turbines needs specific materials. These include copper, lithium and nickel—all commodities where Australia has world-leading reserves.

We have outstanding research capabilities and innovative people, and a track record for contributing globally significant technologies.16 For example, by some industry estimates, solar photovoltaic (PV) technology developed by UNSW is now used in almost 80% of today’s global solar PV manufacturing.

The scale and speed of market transformation in clean energy and recycling—supported by government policy and private investment—positions Australia to create, scale-up and produce manufactured solutions in these growing sectors. Industry and government collaboration can build on the MMS and other elements of Australia’s domestic policy environment to make this happen.

As well as creating prosperity and stable, well-paying jobs for Australians, manufacturers will be part of the solution for major environmental challenges. They will keep waste out of landfill and oceans, and help reduce emissions in Australia and the world.

Industry structure: understanding the current landscape

Manufacturing in recycling and clean energy is an emerging area.

While the quantitative data to track and describe the sector is still under development, important industry players for recycling and clean energy manufacturing include:

- ‘greentech’ start-ups and SMEs developing advanced intellectual property
- established, usually larger, manufacturing businesses transitioning their facilities or product offerings to take advantage of new technology and market trends which demand more sustainable ways of using energy and materials
- consumer-facing brands who are driving demand for clean energy or recycled solutions to meet customer and shareholder expectations.

Generally speaking, small players possess the focus and agility to design and develop innovative products. Big players possess the capital and reputation to commercialise and scale these innovations quickly. Driven by these core players, industry growth can generate flow-on opportunities for other manufacturers (for example contract fabricators) to ‘spin in’ to recycling and clean energy.

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14 Australia has the highest per capita solar resource in the G20 and some of the world’s best wind resources on our coasts. These provide a natural advantage for energy-intensive green manufacturing and for development of technologies to harness renewable energy. Sources: Technology Investment Roadmap (2020), National Hydrogen Strategy (2019)
**Barriers to scale**

In the recycling sector, large vertically-integrated companies who collect, process and remanufacture waste occupy a strong market position that helps provide the volume, stable demand, and economies of scale needed to make recycling activities viable. This market structure, and the complexity of logistics and processing systems designed around it, can deter new market entrants or make introducing innovations difficult. More competition in materials processing could help drive down costs and improve quality of feedstocks for remanufacturing. Policies such as the waste export ban could also change this market structure by encouraging new business models and create opportunities for new kinds of business collaboration.

In the clean energy sector, Australia captures only a small fraction of the supply chain for wind, solar and battery projects. Technologies for manufacturing many low emissions commodities, and the markets that value these characteristics, are still emerging. The extreme competitiveness and low margins of the global industry, combined with the relatively small scale of Australia’s domestic market, has made clean energy manufacturing opportunities hard to capture. This could change given the potential scale of future market niches (for example, clean hydrogen export) and the potential for innovative products (such as from greentech start-ups) to offer compelling customer propositions that capture export opportunities.

Finding demand is a common barrier for emerging manufacturers in recycling and clean energy. Co-investments that reduce production costs, bring together manufacturers and their customers to create new products for unmet needs, or that help manufacturers tap the potential of large projects or large customers, are key. These need to work alongside other policy mechanisms that enable, shape and create markets for green products, such as standards, product certification, and government procurement. This can complete a virtuous circle that supports greater scale and improved cost competitiveness in an emerging industry (see Figure 4).

**Figure 4: Demand, scale and cost competitiveness.**  
(Adapted from Australia’s National Hydrogen Strategy (2019))
**Recycling**

For recycling, the key challenges relate to building market acceptance for recycled material—by consumers, manufacturers and industrial designers. Product and market development can improve the outlook for investments that improve the cost and quality of materials, or bring more recycled feedstock into production.

While demand for recycled materials is growing quickly, in absolute terms it remains small compared to the volume of waste material we produce. Greater market acceptance—from the end consumer all the way back through the manufacturing chain—is needed for demand to grow. For upstream manufacturers—for example recyclers and material processors—this lack of demand has deterred investments that could address costs and quality issues. This is even the case for recycling technologies which are already available and commercially proven overseas. Further downstream, the cost and quality of recycled materials compared to virgin inputs have made them difficult for manufacturers to use in the products they make. If manufacturers can develop markets for their products, this will improve the outlook for investments needed to break this sequencing dilemma.

Through the National Waste Policy Action Plan, governments and industry are investing in better collection, sorting, processing and transport systems, generally operated by large companies with extensive infrastructure including material recovery facilities (MRFs). This is reducing contamination and the cost of post-consumer material streams, but while essential, it is not sufficient to seize opportunities. We also need post-MRF manufacturers (or ‘remanufacturers’) to step up, and invest in retooling processes to shift to secondary materials or designing compelling products that can meet customer needs better than current offerings. This part of the manufacturing chain is much less concentrated, presenting opportunities for emerging new entrants. The MMS can help manufacturers build this capability and work with end-customers to design and manufacture products which meet their requirements.
Clean energy

For clean energy, the challenges relate to tapping into the demand on offer from global markets and large-scale investment, and developing manufactured products that meet untapped customer needs, attract investment and capture market share in a highly competitive and innovative sector.

Investor and market appetite for clean energy in Australia and around the world is undeniable, but Australia is yet to convert this into large-scale manufacturing opportunities. Most of the manufactured inputs required by large projects—mostly solar PV and wind—are currently made offshore. Australia’s domestic supply chain for clean energy components is undeveloped. Adoption of clean energy for industrial manufacturing is often an early-stage proposition, especially in heavy manufacturing processes.

Globally, clean energy is an extremely competitive industry. While this has contributed to plummeting costs that are critical to the market’s continued development, returns on capital are being pushed lower and lower, which has put pressure on manufacturers in the industry. In this context, it is critical for competitive Australian firms to effectively differentiate their products, develop strong brands, and command market premiums.

As clean energy investment in Australia continues to grow and reach into world-leading niches (such as export-oriented renewable energy, distributed renewable energy, remote energy, clean heat and hydrogen) there is scope to tap into advanced manufacturing opportunities flowing from large-scale projects and innovation needs. For example, adapting technologies for Australia’s rapidly changing electricity system or harsh climate conditions could be opportunities for companies to develop exportable products in valuable niches.

Success will be underpinned by innovation and novel products—risky areas for private finance to go without public risk sharing. The Government provides a range of support mechanisms across the clean energy innovation chain including funding through ARENA and commercial finance through the Clean Energy Finance Corporation. These work alongside Commonwealth and state government clean energy policies that stimulate clean energy demand. But there are areas of weakness in accessing finance for late-stage commercialisation and taking new innovations to impactful scale. The MMS could support the collaborations required within industry to scale quickly and grasp these opportunities.

Additional barriers to scale for recycling and clean energy are discussed in Appendix B.
3. Vision—Recycling and clean energy

To develop world-leading advanced manufacturers that seize opportunities from sustainability, the clean energy transition, and waste reduction demands by leveraging Australia’s advantages in innovation, technology, renewable and mineral resources, and our onshore industrial base.

By the end of the decade Australian manufacturers will be world leaders realising extensive opportunities across recycling and clean energy. They will get there by successfully playing to key areas of Australia’s industrial advantage, building on growing global demand for green, clean products, and collaborating across material and energy supply chains to mobilise large-scale investment.

The scale of Australian clean technology adoption will have helped propel development of scaled-up commercial innovations that build on our current research excellence. Mineral resources and waste materials will be transformed into higher value products onshore, not just shipped overseas. Clean energy will be extensively deployed with more Australian manufactured inputs used in their construction. Low-cost renewable energy will enhance manufacturing processes and make onshore manufacturing more competitive. Artificial intelligence and digital technologies will support circular economy and distributed energy innovations. Australian industries—such as metal ore mining and energy-intensive manufacturing—will be preserved and expanded as the economic potential of recycling and clean energy is unlocked.

Recycling and clean energy will be recognised for creating prosperity and diverse, well-paying manufacturing jobs for Australians, as well as helping to tackle global environmental challenges.

4. Future growth opportunities

There are opportunities for Australian manufacturers to take advantage of the global transition to clean energy and a circular economy to build scale and competitiveness. Feedback from industry stakeholders highlighted areas of opportunity including:

- manufactured products that enable recycling or production of clean energy: examples include renewable energy components and equipment, or manufactured products and technologies that facilitate easier resource recovery at end-of-life.
- manufactured products that use recycled materials or clean energy as inputs: such as ‘green’ plastics or steel.

Opportunities across these areas are growing quickly. Through detailed analysis, public consultation, drawing on industry experts’ views, and reports, the following opportunities have been identified for the Australian recycling and clean energy industry to scale over the next decade.

Table 1: Summary of opportunities

<table>
<thead>
<tr>
<th>Recycling</th>
<th>Manufactured products that enable recycling or clean energy</th>
<th>Manufactured products that use recycling or clean energy</th>
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<tbody>
<tr>
<td></td>
<td>• Recyclable products and packaging</td>
<td>• Products made from recycled feedstock, such as plastic or organic waste</td>
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<tr>
<td></td>
<td>• Cleaner feedstocks for remanufacturing</td>
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<tr>
<td>Clean energy</td>
<td>• Components for large industrial systems, such as hydrogen tech, HVDC tech, thermal energy, and modularised renewables</td>
<td>• Energy-intensive manufacturing with clean energy, such as low emissions steel and aluminium</td>
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<td></td>
<td>• Enabling technologies for distributed energy, such as microgrids, inverters, EV chargers and next-gen PV modules</td>
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<tr>
<td></td>
<td>• Moving up the value chain, from mining to making, such as batteries and battery precursors</td>
<td></td>
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<tr>
<td>Overlapping manufacturing opportunities</td>
<td>• Advanced materials, for example, carbon fibre and graphene</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Recycling clean energy components such as PV panels, wind turbines, and batteries</td>
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High-value, non-production activities in the value chain like design will help enable competitive onshore production in these areas. Having the capability to manufacture physical products will also enable manufacturers to capture additional forms of value through other services. In recycling, value-adding non-production activities could include designing products for locally available recycled feedstocks, or offering end-of-life services to help companies meet product stewardship obligations or demonstrate sustainability credentials to consumers. In clean energy, it could include designing products to integrate with industrial processes or the electricity system, or providing whole-of-life servicing, maintenance and repairs. All will be important for competitive manufacturers to generate full value from their investments.

Recycling

Getting access to high-quality, low-cost material inputs is historically one of Australian manufacturing’s competitive pressures. The road map taskforce sees a significant opportunity to address this by better realising Australia’s potential to turn waste into resources.

Making recyclable products and cleaner feedstocks for remanufacturing

To integrate recycled materials into manufacturing processes, industry will need to scale-up innovative solutions so secondary materials can be captured in purer forms at lower prices. This will be an important enabler for downstream manufacturing opportunities, and means developing products and packaging that are recyclable, as well as developing technology capabilities that allow more material to be recycled into useable feedstocks. Developing manufacturing of recyclable products and packaging will also support the Government’s waste agenda.

Identified opportunities include:

- **Product design**: ‘designing for circularity’ is critical to improving the quality of our waste streams and making products easier to re-use. This includes designing out problem materials, reducing the number of materials in a product, and designing for simple disassembly and recyclability. Australia can leverage our strengths in design, research, and product engineering. Good design will support smarter sorting and automation technologies. Innovations in design could be patented and then exported to global manufacturers and brands.

- **Smart sorting and automation technologies**: Adopting innovative recycling technologies can significantly improve processing efficiency and material consistency, reducing the cost gap between virgin and recycled feedstocks.18
  - Digital technologies, such as AI and sensor networks, can quantify and track materials as they are processed through mechanical recycling facilities and help detect and sort materials automatically. These technologies can then make predictions to inform planning, optimise logistics, and automate processes.
  - Traceability technologies like pallet barcodes, blockchain and digital product passports could enable more sophisticated material trading systems that make material sources transparent to consumers. This could help materials remain in circulation and make recycled feedstocks more appealing to customers seeking a ‘green’ edge.
  - Physical technologies, such as robots, can increase recovery rates, more efficiently sort materials, and handle materials that are unsafe for workers. They can then remanufacture them into new products or energy. Existing technologies such as automated guided vehicles, sensors and predictive analytics systems can also help with improved waste source separation.

- **Feedstock recycling**: Plastic products that are difficult to mechanically recycle due to their low quality or composite nature could be converted back to their monomers or petrochemical components. These can be used as direct substitutes for virgin materials in manufacturing new products, which is particularly useful for products like food packaging which must adhere to strict food safety standards. This is yet to be deployed at commercial scale in Australia but could be integrated into the supply chains of plastic and chemical manufacturers.19 Clean energy could also allow these energy-intensive processes to be performed with less cost and environmental impact.20

- **E-waste processing**: Emerging techniques to manage hard-to-recover and hazardous e-waste could include improved mechanical, optical, thermal, chemical, biological and nano-processing.21 To recover maximum value from e-waste, industry needs to overcome the barrier of decentralised, irregular material flows that are difficult to gather economically. This requires developing and scaling-up small scale processing technologies such as microfactories and other collection solutions, such as the National Television and Computer Recycling Scheme.22

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19 Ibid
21 Infrastructure Victoria (2020) Advice on recycling & resource recovery infrastructure April 2020
22 Microfactories developed by UNSW specialise in reforming e-waste (and other hard-to-recycle waste) into high quality ‘green’ materials. These include plastic filaments and metal alloys that can be used for further advanced manufacturing. Victoria has recently acquired an e-waste processing technology known as BluBox. BluBox is a 40ft container that can process next generation e-waste such as flat panel displays, smart phones, tablets and laptops. Instead of exporting it, this technology allows complete processing of e-waste in Australia, and scales up our processing capability. For example, it usually takes 125 hours for a person to manually dismantle one tonne of LCD televisions, while the BluBox can do the same in one hour.
Products from recycled feedstock

International and domestic markets are looking to purchase more sustainably sourced products, and Australian feedstock suppliers are seeking markets for reprocessed materials. Australian manufacturers have an opportunity to complete this loop and develop new products that integrate recycled materials without compromising product integrity, function or cost. This will require investment in the development, testing, re-tooling, and transforming of production lines.

While the quality and potential of each material stream and its sub-streams varies, manufacturers can press for higher value applications of the available feedstocks (see Appendix C for the recycling rates of different waste streams). Higher value applications could include ‘upcycling’ into higher value products, re-use, or remanufacturing into closely equivalent products. Lower value, high volume applications (such as road base, road surfaces or fuel) can also have a role in establishing scale in the industry which can make higher value products more economic in the longer term. The ideal outcome from this road map is enabling manufacturers to derive the highest value use of recycled materials.

Leading opportunities to capture value include:

- **Plastics:** Rising demand for plastic products and increasing environmental concerns are driving strong growth for the global plastic recycling industry which was valued at $48.6 billion in 2017. There are established markets for PET and HDPE, but markets for mixed plastic have not yet been found. This has led to abundant unused material stockpiles by mechanical recycling facilities and re-processors. Both provide opportunities for Australian manufacturers.
  - Under the Australian Packaging Covenant Organisation, over 1500 industry participants including supermarkets, packaging companies, and retailers are pursuing targets to make all packaging recyclable, reusable or compostable; make 70% of plastic packaging recycled or composted; and have 50% recycled content across all packaging by 2025. This is driving demand for recycling packaging solutions.

- **Glass:** Glass has significant opportunities for new value capture where they are particularly high-value or high quality, for example Australia’s 13 million solar panels. CSIRO identify that tracking high-value glass flows, improving design to increase recovery rates, and encouraging innovation in a market of a few large players will contribute to Australia’s transition to a circular economy.
  - Glass sand reprocessing for regional roads could enable more use of recycled glass where the high-value glass cannot be collected at scale.

- **E-waste:** E-waste is the fastest-growing waste stream in Australia and the world. In 2019, the combined value of raw materials in electronic waste in Australia and New Zealand was estimated to be approximately $900 million. Less than 10% was recycled compared to a global recycling rate of 17%. Scarc, and valuable raw materials, such as gold, platinum, cobalt and rare earth elements are being lost through poor e-waste management. As much as 7% of the world’s gold may currently be contained in e-waste, and overall e-waste is richer in metal than land-mined ores. The value of materials in electrical and electronic goods like circuit boards, along with increased privacy concerns around safe disposal of personal equipment, provide opportunities for manufacturers in Australia to follow the lead of pilot plants overseas to integrate captured materials into their processes. Techno-economic analysis of processing technologies suggests profitable projects could be set up in Australia above the scale of 30 000 tonnes per year.

- **Textiles:** More than 90% of textile waste (including leather and rubber) currently goes unrecovered in Australia, one of the lowest rates of any material stream. Industry has the opportunity to transform this waste (mostly from clothing) into new raw materials, and identify high-value recycling streams and sorting processes that meet commercial-scale needs. Less than 1% of global material used to produce clothing is recycled into new clothing, representing a loss of more than $120 billion worth of materials each year. Demand for clothing is growing quickly, with clothing sales expected to triple by 2050. Opportunities for industry include recycling cellulose-based fibres (such as cotton and viscose), and finding solutions to reduce costs of recycling of blended materials. Potentially recoverable materials include PET, cotton, nylon, acrylic, and viscose. These could be used in new products by the textile manufacturing industry or in other manufacturing sectors, such as packaging.

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27 Ibid
28 Infrastructure Victoria (2020) Advice on recycling & resource recovery infrastructure April 2020
36 Ellen Macarthur Foundation (2017) A new textiles economy: redesigning fashion’s future
Biofuels from waste—including organic, agricultural and forest residues—are an emerging opportunity, where biofuels can be used as a feedstock for manufacturing or as fuel for transport and machinery. Researchers at RMIT have manufactured concrete using rubber tyres and demolition waste to create a recycled alternative that is up to 35 per cent stronger than traditional concrete. Waste glass is also an emerging option to improve the sustainability of the energy-intensive product, and create a market for waste glass.

**Cement:** More sustainable forms of cement and concrete are under development. Wagners has developed a concrete that uses industrial waste by-products, slag and fly ash as a binding agent, resulting in 80 to 90% lower emissions than Portland cement. Researchers at RMIT have manufactured concrete using rubber tyres and demolition waste to create a recycled alternative that is up to 35 per cent stronger than traditional concrete. Waste glass is also an emerging option to improve the sustainability of the energy-intensive product, and create a market for waste glass.

**Tyre-derived products (TDP):** From 1 December 2021 Australia will prohibit the export of used, unprocessed tyres so alternative uses will need to be found to avoid waste management issues. The most common TDP is crumb rubber for use in roads and playground surfacing. We can also increase the market for TDPs by developing innovative new uses, such as spray-on concrete. In 2018-19 only 14% of Australia’s tyre consumption were processed into TDPs or re-treaded for reuse. The rest was exported, sent to landfill or stockpiled.

**Organic waste-derived products:** Under the National Waste Policy Action Plan, governments have set a target to halve the amount of organic waste (mostly livestock manure, bagasse, food and garden waste) sent to landfill by 2030. Around half of organic waste is unrecovered in Australia. The most common uses of recycled organic waste are composting, mulching, and processing into fertiliser and livestock feed, but innovation may make higher value manufactured products more feasible.

- Biofuels from waste—including organic, agricultural and forest residues—are an emerging opportunity, where biofuels can be used as a feedstock for manufacturing or as fuel for transport and machinery. Geoscience Australia observe Australia’s potential bioenergy resources are large. Producing 20 gigalitres of biofuel per year in Australia could support creation of up to 250,000 jobs mostly in regional areas, and up to $30 billion of investment.
- Synthetic biology technologies could use organic waste and crop surplus to produce new foods, animal feed and nutraceuticals, or biomaterials for textiles (such as Bolt Threads’ mushroom-based leather ‘Mylo’) and other applications. Val馿ration technologies can also extract valuable components, such as starch and oils, to sell at higher prices.

**Clean energy**

Large-scale deployment of clean energy provides Australian manufacturers with opportunities to tap into supply chain opportunities for manufactured hardware and downstream components. Access to low cost clean energy can enhance the competitiveness of energy-intensive manufacturing and for pursuing markets that increasingly value low emissions industrial products.

**Making components for large-scale and industrial renewable systems**

Investment in large-scale and industrial renewable energy projects in Australia provide a significant opportunity to develop domestic manufacturing supply chains for the components which feed into those projects.

Large industrial companies—including miners, manufacturers, and energy exporters—are increasingly moving to adopt clean energy to access the benefits and opportunities of new technology and address demands from shareholders and customers. For example, Fortescue has disclosed its intention to develop 300 GW of clean energy capacity globally. That is equivalent to around 6 times the current National Electricity Market capacity.

Large industrial applications are a relatively new frontier for clean energy technology. Manufactured solutions are not always commercialised or in production at scale. Australia has major opportunities where:

- global incumbency is not yet established,
- we have emerging domestic demand, and
- we have innovation and intellectual property advantages.

37 The Fifth Estate (n.d.) The latest in low carbon concrete accessed 9 February 2021
38 University of Sydney (2020) “Green” cement pour yields concrete results, accessed 27 January 2021
39 From 1 December 2021 tyres can only be exported for re-treading to a verified re-treading facility or if processed into crumbs, buffings, granules, shreds or tyre-derived fuel.
43 Ibid.
44 Geoscience Australia (n.d.) Bioenergy accessed 19 February 2021
45 CEFC and ARENA (2019) Biofuels and Transport: An Australian opportunity
46 Australian Energy Regulator (n.d.) Annual generation capacity and peak demand—NEM accessed 1 February 2021
Where this occurs, Australia could have the competitive elements to become a major global manufacturer. Opportunities could include:

• **Electrolysers** (and other hydrogen production technologies) are in an early state of global scale-up. Proposed electrolyser demand from Australia’s largest proposed hydrogen project would be more than 100 times greater than global electrolyser shipments in 2018.48 Australia could leverage its market scale and RD&D strength to establish relationships with global suppliers and expand our role in the value chain.

• **High voltage direct current** (HVDC) transmission technology is advancing quickly. Industry is monitoring proposals such as India’s ‘One Sun, One World, One Grid’ project and potential international electricity interconnections among Southeast Asian countries. Large local HVDC projects, like the proposed Australia-ASEAN Power Link, could present an opportunity for Australia to add value to aluminium and copper resources, and become a manufacturing hub of speciality transmission cabling for the region.

• **Thermal energy** solutions are required for some large industrial systems that need to run 24/7 or need clean heat. A number of world-leading Australian companies such as Vast Solar, Raygen, Graphite Energy, 1414, CCT Energy, and MGA Thermal are developing innovative technologies to provide this. If these technologies can be fully commercialised, they will have global application to help decarbonise industrial energy systems.

• **Scalable, modularised, and rapidly deployable components** that allow renewable energy systems to avoid site-specific engineering or construction logistics, such as SB’s Maverick system, offer a compelling value proposition as corporate and industrial demand for clean energy accelerates worldwide. Assembling more components in manufacturing facilities can reduce project development time, reduce costs considerably and shift employment from a short-term construction workforce to a stable, skilled manufacturing workforce.

There are opportunities for firms to become more competitive in our domestic market. Renewable energy project developers who prioritise local content have historically had limited options. For example, Australia currently has one solar panel manufacturer and one manufacturer focused uniquely on wind towers. Both have struggled to manage fluctuating demand.49 The growing scale of Australia’s onshore demand, including from renewable energy zones and export-oriented renewable projects, could provide such producers with the opportunity to scale production and demonstrate capabilities to integrate system design, manufacturing, installation, servicing and end-of-life management.

With market volume and initial scale-up support, more local manufacturers could be competitive in more parts of the clean energy supply chain. This offers significant opportunities to onshore industrial production, especially for clean energy megaprojects which could have the scale to support completely new approaches. For example, some parts of renewable energy systems are hard to transport, such as wind turbine blades, wind turbine towers, transmission towers, heliostats, and solar panel frames and trackers, increasing the business case for manufacturing them here. Balance of plant equipment for large-scale energy systems may also need to be tailored to integrate with site or process specific requirements or meet Australian standards or regulations.

### Making enabling technologies for distributed energy systems

While industrial users are seeking larger renewable energy systems, small-scale energy users, such as households, and the energy systems they are part of, also demand new manufacturing solutions.

Electricity networks are becoming more distributed and more decentralised. Australia is at the forefront of these accelerating trends, with more than one-in-four households adopting rooftop solar.50 Digital and smart technologies are essential for managing these systems and Australia has strong capabilities. Data collection, forecasting, automation, controllability, and performance prediction will be needed to help the elements of these systems, like rooftop solar PV, behind-the-meter batteries, and electric vehicles work harmoniously to provide greater value and maintain system security. These capabilities will need to be embedded in the equipment these systems use.

The road map taskforce suggests Australia, as one of the most decentralised energy systems, has a platform to develop and manufacture some of these important enabling technologies, including for international customers in future waves of energy transition. Our competitive proposition will generally flow from quality and innovation, rather than cost competitiveness on low margin products like photovoltaic cells. Australian manufacturers can also be trusted technology suppliers for customers who value cybersecurity or sovereign supply in digitally-enabled devices for distributed energy systems.

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48 DISER estimate based on project plans for Asian Renewable Energy Hub and BloombergNEF data on global electrolyser installations.

49 Industry consultation

50 BloombergNEF
Key opportunities to provide globally exportable solutions include:

- **Microgrids**, and similar systems like remote area power systems (RAPs) and standalone power systems, can provide flexibility, resilience, and lower costs for more distributed energy systems. Australia is in an almost unique position as an advanced economy with a relatively high proportion of energy demand in remote locations (for example mining users). We also have world-leading experience in developing systems like these which could be applicable to many potential customers. This includes emerging markets in Africa and the Indo-Pacific, who are looking to bring electricity to more citizens and lack legacy grid infrastructure.

- **Advanced inverters, converters and EV chargers** are needed to help connect DC power systems (such as solar, batteries or electric vehicles) into our AC-based power grid and maintain system security. New functions need to be brought to commerciality quickly, for example, to enable synthetic inertia, voltage control, and observability and controllability for grid operators. These will require manufacturers to develop integrated software and hardware solutions. Australian companies such as Tritium are already excelling at developing these and exporting them to international markets.

- **Next generation solar PV modules and arrays**. This would involve translating cutting-edge Australian IP into advanced products, such as:
  - specialised PV manufacturing process improvements (such as replacing expensive metal inputs or making high efficiency solar cells)
  - innovative pre-fabricated modules and arrays.

Competitive opportunities for solar PV modules in the domestic market will be assisted by the difficulty of transporting heavy glass products.

Enabling technologies for distributed systems (such as digitalisation and moving to modular solutions) will also be applicable in large industrial systems. There may also be opportunities to manufacture distributed energy products like batteries and electric vehicles (including buses and heavy vehicles), building on our position as a leading resources nation.

**Moving up the value chain, from mining to making**

Electric vehicles, batteries, and other advanced clean energy technologies require critical minerals and important base metals. Australia supplies many of these raw inputs and already participates in the value chain for these products.

Australia has strong prospects to capture more value by moving ‘up’ this value chain—that is, moving beyond resource extraction to more advanced onshore processing. This includes processing of primary ores into the value-added oxides, alloys and precursor materials which feed into more advanced manufacturing products (see the Resources Technology and Critical Minerals Processing road map).

Several Australian companies are also pursuing battery manufacturing and similar opportunities, by developing niche or specialised applications. For example, current generation batteries can be prone to performance and efficiency issues in hot climates, and batteries suitable for Australia’s harsh climate could have wide applications in developing markets. The energy management and cybersecurity functions of embedded software electronics can also be effective product differentiators.

Companies such as Magellan Power specialise in providing renewable energy and storage systems to the Australian mining industry. Energy Renaissance is looking to apply unique intellectual property to manufacture hot climate, reinforced battery systems from its facility in the Hunter Valley. Australian companies have also developed grid management solutions enabling batteries to be controlled in virtual power plants and for system security.

These domestic supply chains could be scaled-up in future as more value-added minerals processing takes place in Australia.

**Energy-intensive manufacturing from clean energy**

In the longer term, falling renewable technology costs and harnessing carbon capture, use and storage (CCUS) could see Australia achieve an industrial advantage in energy-intensive manufacturing. Along with other clean energy technologies discussed in this road map, manufacturers adopting clean heat technologies (including solar thermal, heat pumps, hydrogen and bioenergy) will be important for producing low emissions industrial products. These include steel, aluminium, cement, and ammonia (as both a fertiliser and possible low emissions fuel). Recycling facilities are also large energy users in their own right.

The First Low Emissions Technology Statement has identified the opportunity to preserve and expand the onshore manufacturing of energy-intensive products, and set priority technology stretch goals to reduce the cost of low carbon materials.

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51 Australia’s mining and resources sector is increasingly turning to microgrids incorporating a mix of technologies to ensure cheaper, cleaner, reliable electricity. For example, Agnew gold mine has a microgrid including an 18 MW wind farm, a 4 MW solar farm and a 15 MW battery system. The solar component was accredited in August 2019 and the wind component in February 2020. DeGrussa, Granny Smith, and Nova Nickel mines provide other accredited small-scale examples of microgrids in mining. Source: Information from the Clean Energy Regulator (2021).

Australian lithium ion battery (LIB) waste is growing by 20% annually, as a direct result of increased uptake of advanced vehicles. Others could help address recycling challenges, reduce landfill and protect oceans by replacing problematic or unnecessary plastics.

Development of new alternative materials can help make products more durable, enable more sustainable production, and allow for more material and product re-use and manufacture, for example in bio-based composites or synthetic textiles derived from waste.

Australia has advanced materials manufacturers, such as Omni Tanker and Carbon Revolution moving to scale-up production based on their innovative IP. Growth companies like these may represent a leverageable position to use Australian IP to support local jobs and potentially anchor adjacent industries using composite material capabilities that are highly transferable to other sectors.

Overlapping manufacturing opportunities

Recycling clean energy components and batteries

Manufacturers are well positioned to offer whole-of-life servicing and maintenance of clean energy equipment and components like batteries. This extends to end-of-life solutions.

- **Solar PV:** By 2050 it is expected there will be over 1,500 kilotonnes of waste from retired solar panels, up from a mere 2.7 kilotonnes in 2018. A typical solar PV module consists mostly of glass, then polymer, aluminium, silicon, and copper. Dissolving the glue that binds together a module’s components is difficult, and it is not uncommon for entire systems to be replaced prematurely because of damage to one part. Improving the technical capability of disassembling a solar PV module (as well as addressing the initial design), will improve resource recovery while minimising waste to landfill.

- **Wind turbines** are also complicated and costly to disassemble. While there are recyclable materials in the components of the turbines—such as concrete, steel and copper—blades are primarily made from composite materials which are not yet commonly recyclable. The standard lifetime of a wind turbine is 20-25 years, an age approached by only 2 of the 101 wind farms in Australia. Nonetheless, the capacity to recycle and remanufacture them will need to be developed soon.

- **Battery recycling** opportunities include ‘second life’ applications (e.g. transfer of refurbished batteries from transport to stationary applications) and deconstruction of batteries into basic materials.
  - Australian lithium ion battery (LIB) waste is growing by 20% annually, as a direct result of increased uptake of rechargeable electronic equipment and electric vehicles. In 2016, only 2% of the 3,300 tonnes of LIB waste we generated was collected and exported for offshore recycling. By 2036 LIB waste generation is forecasted to reach between 100,000 and 188,000 tonnes—an increase of up to 5700%. The potential for value capture for Australia is in the billions.

  Manufacturers can improve their competitive advantage by offering pre- and post- production services to help address end-of-life issues with clean energy technology. Companies who can develop solutions to these emerging issues, and integrate end-of-life solutions to their service offerings, will have an advantage against international competitors and opportunities to capture market share.

Making greentech products from advanced materials

High-quality, innovative, and advanced materials could offer Australia a competitive edge. Advanced materials could play important roles in assisting energy transition, for example carbon fibre in new wind turbine blades or light-weighting advanced vehicles. Alternative conducting materials, for example using graphene, could enable advanced electricity and battery technologies. Others could help address recycling challenges, reduce landfill and protect oceans by replacing problematic or unnecessary plastics.

Development of new alternative materials can help make products more durable, enable more sustainable production, and allow for more material and product re-use and manufacture, for example in bio-based composites or synthetic textiles derived from waste.

54 RE100 (2020) QLD’s biggest zinc refinery joins RE100—Sun Metals commits to use 100% renewable electricity accessed 1 February 2021
55 Clean Energy Council submission
56 Ibid
58 Clean Energy Council submission
60 Ibid
5. Enablers

There are some key enablers for realising the manufacturing potential of recycling and clean energy.

Developing world-leading greentech products

Investors are keenly aware that in rapidly changing and growing markets such as recycling and clean energy, the companies who ‘win’ are those who turn an innovation edge into world-leading products that offer compelling value to forward-looking customers. This supports them to remain competitive in a market that is being continually reshaped by increasingly stringent expectations of consumers and policymakers for cleaner, greener products.

The road map taskforce sees a number of innovative products and processes for clean energy and recycling that could be brought out of the lab and onto the production line. While the calibre of Australia’s research in clean energy and recycling is unquestioned, as in other sectors, we have been less successful at development, demonstration and commercialisation. This calls for more focus on honing Australian industry’s skills in late-stage commercialisation (i.e. TRLs 7-9 and CRI 2+), and advancing technologies such as solar thermal, thermal energy storage, chemical recycling, and recycling for composite materials like carbon fibre. For additional explanation of Technology Readiness Levels and Commercial Readiness Index, see Appendix D.

Specialised or incremental innovation in more established products or processes is an equally high priority for realising our vision. This includes innovations in product design (e.g. to improve user experience, adapt for Australian conditions or to support re-use), or to embed automation, artificial intelligence or other Industry 4.0 capabilities, which can lower manufacturing and supply chain costs, and make new processes possible. These innovations may not be as transformative to the workings of energy and material systems, but they will be essential elements for Australian manufacturing businesses to compete globally.

The Modern Manufacturing Initiative can assist with this by supporting manufacturers to commercialise products and collaborate across the supply chain. It will complement initiatives such as the Future Battery Industries CRC to help bring world-leading products to market.

Support domestic manufacturers to benefit from industry growth

For emerging sectors like recycling and clean energy, the challenges of commercialising innovation and scaling up the industry are closely entwined. Initial demand is commonly a missing piece. Policy actions which create and catalyse demand are important, as is tapping and unlocking what is already available.

Parts of clean energy and recycling are already scaling quickly, supported by complementary government co-investments. The National Waste Policy Action Plan is driving the private sector to set packaging targets, develop product stewardship schemes, and take advantage of improved waste infrastructure, improving feedstock quality, and new standards for recycled materials. Clean energy megaprojects and renewable energy zones could signify new sources of demand. Government’s task, through the Modern Manufacturing Strategy, is to work with competitive enterprises to help convert this growth into domestic manufacturing opportunities.

The road map taskforce considers that some Australian market demand currently serviced by manufacturers overseas could be met by more Australian companies. Competitive enterprises are already doing this by offering better quality products based on higher sustainability criteria, fewer supply chain risks, and more opportunities for customised design and post-sales services.

The Modern Manufacturing Strategy could help more manufacturers build and market these capabilities to customers. This will encourage large commercial and industrial customers to seek opportunities to ‘re-shore’ production by testing, or re-testing Australian manufacturers’ competitiveness.

Mobilise large-scale investment in new ways of using energy and materials

Large-scale investment can be mobilised through collaborations which ‘bring it all together’ across translation, integration, and collaboration activities. Consortiums with partners that bring complementary strengths from across the innovation chain, value chain, and supply chain can cooperatively shape a pathway to scale for domestic manufacturers. In the recycling sector (Figure 5), these partners could include all of the business actors from the consumer back to the manufacturers who would support a move from a linear ‘supply chain’ to a ‘supply circle’ that avoids waste and produces more economic value. This could require increased collaboration between manufacturers and feedstock suppliers to get suitable material at competitive cost; collaboration between designers, manufacturers and retailers (or brand owners) to design recycled packages or products which meets the retailer’s requirements; and collaboration on processes to allow the customer to return products for maintenance, re-use or recycling.
In the clean energy sector (Figure 6), large-scale investment could be drawn to manufacturing through consortiums that include hardware manufacturers, large clean energy project proponents (especially export-scale), energy-intensive manufacturers and the resources sector. Collaborations could result in Australian-based component manufacturing and maintenance of clean energy infrastructure, and greater access to clean energy for energy-intensive manufacturing.
Collaborations like these can support emerging companies to crowd-in additional private finance or prepare them to attract additional private capital injections in future through venture capital or public stock exchange listings. The Modern Manufacturing Strategy can help facilitate these.
6. Goals

The road map’s vision is to develop world-leading advanced manufacturers that seize economic opportunities from sustainability, the clean energy transition, and the global effort to create more value from resources and reduced waste. It is based on playing to key areas of Australia’s industrial advantage: innovation, renewable and mineral resources, leadership in technology adoption, and expanding the existing strengths of our industrial base. To seize these opportunities and deliver our vision, the Modern Manufacturing Strategy needs to drive collaborations that:

- Develop world-leading greentech products
- Support domestic manufacturers to benefit from industry growth
- Mobilise large-scale investment in new ways of using energy and materials

Supporting late-stage commercialisation is key; connecting industry with demand and building domestic manufacturing capability is critical. This includes identifying new market opportunities for manufacturers to access global supply chains or global scale domestic projects.

To track the progress of our efforts and actions, a number of qualitative and quantitative goals will provide markers across 2, 5 and 10 year timelines.

### Recycling & Clean Energy

**Developing world-leading products that take advantage of growing demand for clean green products, supporting domestic manufacturers to benefit from industry growth, and mobilising large scale manufacturing investment in new ways of using energy and materials**

<table>
<thead>
<tr>
<th>Success at 2 years—by end of 2022</th>
<th>Success at 5 years—by end of 2025</th>
<th>Success at 10 years—by end of 2030</th>
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| • New technologies and products are technically and commercially proven. More manufacturers are ready to take advantage of accelerating trends favouring sustainable production.  
• Co-investments support manufacturers to develop world-leading products, convert sectoral growth into onshore manufacturing opportunities, and collaboration between businesses. At least some of these co-investments leverage the scale economies of place-based hubs.  
• More businesses are developing pre- and post- production capabilities to enhance their competitive offering to domestic and global markets.  
• In recycling, manufacturers collaborate with suppliers and retailers to bring recycled feedstock into more production processes, and develop products (and end-of-life services) that make reducing or recovering materials easier.  
• In clean energy, manufacturers and other businesses collaborate to develop more advanced equipment and technologies, integrate with global value chains and global scale projects, and bring clean energy into more manufacturing processes. | • Businesses are building on capabilities and products, with continued investment in market-leading innovations and increasing scale. Maturing markets for green technologies and products are helping pull this through.  
• Manufacturers have ready access to cheaper and cleaner recycled materials, and more affordable, clean and reliable energy. Integrating these into production is a common practice.  
• More Australian manufacturers are accessing domestic and international supply chains for large brands and projects.  
• Consortiums with complementary partners spanning the supply chain are tackling barriers to demand, scale, and competitiveness in a coordinated way, and leveraging the unique collaboration opportunities of industrial precincts. | • R&D, design, production, sales and services have positioned Australian manufacturers as leading providers of solutions to help Australia and the world transition to more sustainable energy and material systems.  
• Manufacturers strongly prefer recycled materials over virgin resources, and have access to these at much greater volumes and more competitive prices.  
• Australia is a leading global manufacturing player for key classes of clean energy hardware, providing Australian innovation to the world and to a thriving local pipeline of clean energy deployment.  
• Australia is becoming a globally attractive destination for investments in low-carbon, energy-intensive manufacturing. |
7. Making it happen

This road map focuses on growing manufacturing activities, capabilities and specialisations in the recycling and clean energy sector. To help businesses seize economic opportunities from sustainability trends, the clean energy transition, and waste reduction demands, we have identified key actions that will be implemented as part of this road map.

Key to achieving our goals are the 3 streams of the Government’s $1.3 billion Modern Manufacturing Initiative that will leverage co-investment with states and territories, industry and research institutions:

- Collaboration Stream—will bring together businesses, researchers and investors to build economies of scale and allow them to compete in international markets
- Translation Stream—will support projects to translate good ideas into new or enhanced commercial outcomes
- Integration Stream—will target the integration of local firms into global value chains.

Co-investments to support translation and commercialisation, supply chain integration and collaboration will help Australian businesses develop world-leading products and mobilise large-scale investment. The road map acknowledges that there are significant areas of overlap between these streams. Collaboration is encouraged in all co-investments, and many investments in practice could cut across all 3 areas. For example:

- manufacturing a new product from recycled material could need translation of a new manufacturing process from the lab to the production line, integration with the product requirements of consumer-facing brands, and collaboration across material processors, remanufacturers, and product designers
- manufacturing a new clean energy system at industrial scale could need translation of novel intellectual property, integration with the supply chain for a project (to achieve scale), and collaborations between innovative firms, project developers, and upstream and downstream manufacturers.

The tables below outline key actions across the 3 streams to ensure Government and industry achieve the vision and goals of this road map.

### Actions to support greater commercialisation and translation

**Use co-investment to help businesses find, design, develop and make world-leading product solutions**

This action will directly enable manufacturers to collaborate to commercialise great innovations and de-risk product development. It will enable competitive enterprises to proactively find and create the demand they need by hunting down fresh market niches. It will support product development that brings together manufacturers, suppliers and customers.

It will encourage businesses in different parts of the value chain to collaborate to realise product opportunities such as turning waste into a resource, decarbonising production, replacing problematic materials, or providing a clean technology product.

For example, in recycling and remanufacturing:

- designing out a hard-to-recycle product element (such as in packaging) will probably need a collaborative solution developed by manufacturers and their retail clients that meets product and regulatory requirements.
- finding novel economic applications of underused recycled material streams will likely require collaboration between upstream and downstream manufacturers, so that a material’s distinct properties can be considered in product or process modification.
- building in post-production services, so products can be returned to manufacturers for recycling into new products, will likely require close collaboration between a designer, manufacturer and retailer of that product. It may also require collaboration with providers of enabling digital infrastructure technologies such as Internet of Things, sensors, and artificial intelligence.

In clean energy it could include:

- developing bespoke technology solutions for large, complex, first-of-a-kind projects (for example, clean energy export).
- assisting a small technology provider to quickly commercialise and scale an innovation to grasp a supply chain opportunity.
Actions that support integration with domestic and international supply chains

Use co-investment to encourage large projects or commercial customers to partner with small, innovative Australian manufacturers and integrate them into supply chains

This action will enable manufacturers to collaborate with customers to integrate their products into changing domestic markets, major domestic projects, and international markets.

Co-investment in recycling and remanufacturing can:

- encourage large commercial and industrial customers to investigate opportunities to test the competitiveness of Australian manufacturers in meeting their needs. This could include collaborations which enable Australian manufacturers to accept end-of-life products and remanufacture them for retail lines.
- enable manufacturers to alter their production processes to meet the procurement requirements of their clients (for example, using a recycled feedstock often requires re-tooling and alterations to a production line).
- facilitate contract commitments by customers allowing a manufacturer to demonstrate how a recycled material could be used.

Co-investment in clean energy manufacturing can:

- help manufacturers to integrate their components into large clean energy projects. This will assist small Australian firms to invest confidently in additional production capacity or bring innovations to commercial scale.
- enable manufacturers to alter their production processes to meet the procurement requirements of their clients (for example, integrating clean energy often requires new capital equipment and changes to manufacturing processes).
- facilitate contract commitments to allow an Australian manufactured product to substitute for a product which is sourced from overseas suppliers.
Use co-investment to support scale-up, commercialisation, and collaboration opportunities flowing from industrial hubs

This action will boost manufacturing by helping businesses tap into industrial hubs as a springboard to scale. This can provide manufacturers with greater access to centralised infrastructure, end customers, and co-located services needed for advanced manufacturing.

In this road map’s context, ‘industrial hubs’ are typically imagined as precincts where large-scale transformations of energy and materials occur. Potential examples include resource recovery precincts, hydrogen hubs, and manufacturing precincts in renewable energy zones. They would be focused on scaling up coordinated manufacturing solutions that cut across all of the priority themes for action.

Hubs represent important clusters of demand, which is key to mobilising investment and addressing late-stage commercialisation challenges. They could help enable efficient access to shared infrastructure, facilities and skills. For example:

- co-funding shared facilities where companies could test and validate new products or processes, without disrupting production lines which need to be run highly efficiently to stay internationally competitive.
- attracting global suppliers of manufacturing inputs to Australia, like electronics contract manufacturing, to offer products and services to Australian manufacturers.
- platforms for consortiums to come together and tackle ‘chicken-and-egg’ challenges of scaling demand and supply for emerging industries, or to collaborate across different parts of the value chain.
- leveraging unique innovation opportunities afforded by co-location with industry, to turn industrial hubs into innovation hubs as well.

Globally, innovation hubs have been important in producing leading manufacturing innovations in recycling and clean energy. National Energy Resources Australia have highlighted the international role of clusters in bringing together expertise, technologies, specialised resources, capital and knowledge. This gives participants advantages not available to businesses operating alone.

The road map taskforce has also highlighted international exemplars.

- In recycling, ‘eco-industrial parks’ in South Korea allow waste outputs from industrial processes to become inputs into adjacent industrial processes, through clever co-location.
- In clean energy, Italy’s NOI Techpark has provided business model validation, market entry and other incubation services to support Alpitronic’s emergence as an advanced EV charging hardware provider.

Improving quality and depth of advanced trades will need bigger volumes for training providers and stronger, more consistent signals on common skill needs. Fresh approaches to advanced skill development could be embedded in manufacturer-led collaborations, including at hubs or precincts. These could include:

- collaborating with training providers to identify common areas where programs could support specialised but transferable skills
- co-funding a cooperative program to bring ‘best-of-the-best’ international experts to Australia to do training across a number of sites.

Figure 7 illustrates examples of how collaborating for scale can be supported by common user infrastructure and provide access to greater capabilities. These can support translation of innovation, integration with global supply chains, and other shared capabilities that emerging businesses can’t pull through alone.

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64 National Energy Resources Australia (NERA) submission
Co-investment will be used to complement broader innovation support relevant to recycling and clean energy. This toolkit includes ARENA, the Clean Energy Finance Corporation, the Recycling Modernisation Fund, CRC-Ps, Export Finance Australia and other initiatives (including from state governments). Manufacturers should consider how different elements of their development pathway could be defined or sequenced to align with the timing, scale, nature and intent of different MMI streams as well as other channels for public innovation support.

The MMI is not intended to crowd out other forms of funding and finance. The most compelling suggestions for the MMI are likely to be for co-investments that complement, not duplicate, the intent of other clean energy and recycling initiatives by Commonwealth and state governments.
8. Benchmarks of success

Manufacturing in recycling and clean energy is an emerging area. The quantitative data sources to comprehensively track and describe manufacturers’ engagement with recycling and clean energy are still under development.

To measure our progress against the vision set out in the road map, the following will be monitored over 2, 5 and 10 year periods, dependent on data availability:

- number of new jobs
- increase in profitability
- growth in recycling & clean energy exports
- increase in the number of new products brought to market
- investment in the recycling and clean energy sector
- increase in adoption of recycling or clean energy in manufacturing processes
- increase in economic output per unit of material consumed (material productivity)
- reduced loss of materials from circulation in the economy

This road map aims to take Australia into new and different recycling & clean energy manufacturing activities. New and innovative approaches to capture pre- and post- production activities are under development and may be used to identify and capture this activity in future.

Other benchmarks for success will relate to the priority area’s touch points with adjacent government policies. These include:

- achieving actions and targets for recycling and waste reduction under the National Waste Action Plan
- achieving economic stretch goals for priority low emissions technologies under the Technology Investment Roadmap
- helping businesses and communities capture the benefits and opportunities of low emissions technologies and commodities under Australia’s Long Term Emissions Reduction Strategy.
9. Engagement and partnerships

International partnerships

Expanding our international partnerships in the recycling and clean energy sectors will be key to supporting competitiveness and scale for Australian manufacturers. By attracting international collaborators, we can help manufacturers develop and gain access to valuable innovation. We can also work with like-minded countries to shape and gain access to global markets that will support the industry’s rapid move to scale.

Australia is part of a number of bilateral agreements with other nations to cooperate on recycling and the circular economy, such as Malaysia and the Netherlands. Australia is also undertaking research collaboration activities on circular economy and recycling. In 2020 the Hon Karen Andrews MP announced a $19.5 million boost to a research collaboration between Australia and India for new projects to advance pandemic research and reduce plastics waste. Of this, $4.5 million will support collaborative work led by CSIRO to reduce plastic wastes, build recycling capabilities and inform the circular economy of plastics in India and Australia. The US National Science Foundation’s MULTIPLIER mission sends delegations of US researchers overseas to investigate potential research collaborations and build collaborative partnerships. Australia has been selected for a mission that will focus on the topics of plastics and AI ethics.

The Technology Investment Roadmap is a government plan to accelerate the development of new and emerging low emissions technologies by making them economically competitive with established technologies. This unlocks opportunities for Australian businesses to enter national and international supply chains. This is supported by the appointment of Dr Alan Finkel as Australia’s Special Advisor on Low Emissions Technology, who will assist in brokering new partnerships for Australia.

On the research front, CSIRO has collaborated with international partners to utilise Australian technologies overseas. Our concentrated solar thermal (CST) technologies are being used in Japan and Cyprus to increase their proportion of power generated from renewable sources. CSIRO has also partnered with China to help meet their ambitious CST installation goals, by licensing CSIRO’s low-cost heliostat technology. Australia also participates in the Mission Innovation initiative to accelerate global clean energy innovation. In late 2017 the Australian Government announced a $5 million International Engagement Program delivered by ARENA to forge international collaborations and to participate in projects under Mission Innovation and the IEA’s Technology Collaboration Programs. Australia’s participation in both of these international platforms, which focus on accelerating renewable energy development, will support commercialisation prospects for Australian technologies.

Australia is co-operating with other countries on enabling frameworks for market development in ‘green’ manufactured products. For example, through the National Hydrogen Strategy, Australia has committed to take a lead role in the development of an international certification scheme to facilitate trade and avoid delaying investment. This could eventually extend to downstream products such as low emissions steel. Australia is also engaging multilaterally in key forums to shape the rules for hydrogen trade and investment, share best practices in RD&D, safety and community engagement, and to foster private sector investment. These forums include the G20, the Clean Energy Ministerial and the Hydrogen Energy Ministerial. Australia’s key hydrogen trading partners are set to include Japan, Republic of Korea, and Singapore. Various forms of cooperation have been agreed, such as joint statements on cooperation and memorandums of understanding, which will encourage demand for our Hydrogen Energy Hubs.

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65 CSIRO (2019) Solar field lights up Cyprus; Australian solar shines on Japan, accessed 4 February 2020
Other partnerships

The government will implement a collaborative integrated approach to recycling and clean energy manufacturing in Australia. In particular, we can collaborate to help manufacturers tap industry development potential that will flow from related government initiatives. For example:

- Activating Regional Hydrogen Export Hubs: The Government has announced funding to support the creation of a regional, export-oriented ‘clean hydrogen hub’, comprising co-located hydrogen users, exporters, and bilateral trading partners. This will link with international initiatives. There is a window for Australian manufacturers to provide equipment and components to hydrogen hubs, and take advantage of hydrogen in other manufacturing processes.

- Renewable Energy Zones: The Government is working together with state governments to support the development of renewable energy zones (REZ). These REZs will drive demand for manufactured project inputs and help support clean and secure electricity supply for other manufacturing at scale. The first REZ is planned for Central-West New South Wales, which will unlock up to 3GW of new electricity capacity by the mid-2020s.

- Procurement of recycled materials: The Government is committed to create demand for recycled materials by buying goods with recycled content. Agencies must now consider environmental sustainability and the opportunity to use recycled content when determining value for money in purchasing decisions. Through the National Waste Policy Action Plan, governments are developing standards to support the use of recycled materials in roads and looking for opportunities to use recycled content in the infrastructure we build.

As this roadmap is rolled out, experts from across government departments and agencies such as CSIRO, ARENA, CEFC, DFAT and AusIndustry will assist government and industry by providing expert advice to grow the local manufacturing sector and to identify opportunities to access export markets and supply chains.

Collaboration

Collaboration—either business-to-business or business-to-research—is central to our approach under the Modern Manufacturing Strategy. This resonates strongly in the recycling and clean energy areas.

This roadmap supports the recycling and clean energy sector to build stronger collaborations that engage strategically with the Modern Manufacturing Strategy. Our expectation is that industry, supported by co-investment, will develop diverse collaborations that clear a path to scale and competitiveness and tackle barriers in a coordinated way.

Supporting greater levels of collaboration between government, businesses, venture capitalists, industry experts and researchers will ensure we realise the benefits of innovation, harness our world-class research capabilities and translate our great ideas into commercial outcomes that support new businesses and jobs.
Appendix A

The road map development process

On 1 October 2020, the Australian Government announced $1.5 billion to be invested over the next 4 years in the Modern Manufacturing Strategy (MMS) to help Australian manufacturers become more competitive, resilient and build scale in the global market.

The centrepiece of the MMS is the $1.3 billion Modern Manufacturing Initiative which will allow government to invest in projects within 6 National Manufacturing Priority areas. The 6 National Manufacturing Priority areas are:

- Resources Technology & Critical Minerals Processing
- Food & Beverage
- Medical Products
- Recycling & Clean Energy
- Defence
- Space

Road maps have been developed with industry to set out plans for both industry and Government to strengthen Australia's manufacturing capability. The road maps have been led by 6 industry taskforces to identify and set a future vision for the priority areas with clear goals, opportunities and actions over the next 2, 5 and 10 years.

Members of the industry taskforces were selected based on their expertise across the priority areas, and were supported by technical experts from the Commonwealth Science and Industrial Research Organisation (CSIRO), the Department of Industry, Science, Energy and Resources, the Department of Agriculture, Water and the Environment, and Industry Innovation and Science Australia.

Taskforce deliberations focused on current and future issues, challenges and opportunities to identify actions businesses and government can undertake to support scale, competitiveness and resilience in recycling and clean energy manufacturing in the next 10 years.

Government has also been working with industry beyond the taskforce to understand the needs of the recycling and clean energy manufacturing sector. A public consultation process was held between 23 October 2020 and 9 November 2020 which received 340 responses, including 89 focused on recycling and clean energy manufacturing.

Input on the key strengths, opportunities and solutions to grow manufacturing have been used to inform the road map. The road map was also informed by bilateral meetings with key stakeholders as well as research conducted by the department.
Building on existing findings

This road map builds on the government’s broader economic reform agenda. This includes drawing upon relevant strategies including but not limited to:

- **Technology Investment Roadmap: First Low Emissions Technology Statement** presents a vision of a prosperous Australia, recognised as a global low emissions technology leader. It outlines priority technologies, including clean hydrogen, energy storage and low carbon materials. The statement also covers economic stretch goals, challenges, opportunities, and a Technology Investment Framework.

- **National Waste Policy Action Plan** creates targets and actions to implement the 2018 National Waste Policy. These targets and actions intend to guide investment and national efforts to 2030 and beyond. The plan supports the implementation of better waste management plans by state and territory governments, local government, business and industry.

- **National Hydrogen Strategy** sets a vision for a clean, innovative, safe and competitive hydrogen industry that benefits all Australians and is a major global player by 2030. The strategy outlines an adaptive approach that equips Australia to scale-up quickly as the hydrogen market grows. It includes a set of nationally coordinated actions involving governments, industry and the community.

- **National Food Waste Strategy** provides a framework to halve Australia’s food waste by 2030, with a priority to develop the market for value-added products from food waste.

- **CSIRO’s Circular economy roadmap for plastics, glass, paper and tyres** presents an approach for Australia to transition to a resource-efficient path. The report suggests that Australia has what it needs to adopt a circular economy strategy that will both address environmental issues and foster economic development and employment.

- **CSIRO’s Low Emissions Technology Roadmap** establishes a framework for understanding the range of low emissions technologies available, current barriers and enablers to deployment. The technologies are grouped according to a series of options or ‘pathways’, each have different risk profiles and associated opportunities.
Appendix B

Other barriers to scale

This road map seeks to support the recycling and clean energy national manufacturing priority area to achieve its full potential by overcoming barriers to scale.

The recycling and clean energy taskforce sees the Government’s work to get the economic conditions right for all manufacturers as an important opportunity to improve competitiveness for the sector, particularly in:

- **Attracting investment**: Access to capital can be a challenge in this sector, particularly where companies are commercialising products in emerging sectors. De-risking projects and improving access to debt and equity finance are therefore important. Policies which go to the investment environment, send signals to investors, or more actively provide risk tolerant finance to encourage greater investment are of particular relevance to manufacturers in this area.

- **Energy**: Australia’s capacity to seize manufacturing opportunities in this priority area will require continued work to deliver lower energy costs, especially by continuing to deploy and integrate world-leading levels of clean energy.

- **Skills**: the recycling and clean energy sector is knowledge driven. While we have a skilled and capable workforce, the sector relies on STEM and vocational skills to support emerging clean energy technologies. It also relies on the advanced manufacturing skills needed in product and process design to transition from virgin to recycled materials.

- **Circular economy**: To support the outcomes of this road map, government and industry will need to continue to identify approaches to build circular economy principles such as durability, reuse, reducing obsolescence and planning for end of life reuse of resources into policy and product design.
Untapped value and regulatory pressure on waste exports create manufacturing opportunities in Australia.
Untapped value and regulatory pressure on waste exports create manufacturing opportunities in Australia.

**Potential products**

- **'Second life' uses**
  - Plastics
  - Metals
  - Chemicals
  - New garments, carpets and blankets
  - Insulation materials
  - Silicon
  - Glass
  - Plastics
  - Metals
  - Crumb rubber for soft surfacing, asphalt and tile and rubber glue
  - Pyrolysis into fuel
  - Biofuels
  - Fertiliser
  - Livestock and aquaculture feed
  - Biotextiles
- **Aggregate and fill for asphalt, concrete and roads (from fines)**
- **Food and beverage containers (from cullet)**
- **Paper**
- **Packaging**
- **Toilet paper**
- **Egg cartons**
- **Cardboard**
- **Substitute for virgin crushed rock, asphalt, metals, and timber**
- **Low-grade roads**
- **Pavement sub-bases**
- **Steel**
- **Copper**
- **Lead**
- **Aluminium**

*See next figure*

**Plastics recycling rates, by stream**

![Plastics recycling rates chart](chart)

<table>
<thead>
<tr>
<th>Plastic Type</th>
<th>Recycled Volume</th>
<th>Non-Recycled Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVC</td>
<td>98%</td>
<td>2%</td>
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<tr>
<td>PP</td>
<td>91%</td>
<td>9%</td>
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<tr>
<td>PS</td>
<td>88%</td>
<td>12%</td>
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<tr>
<td>LDPE</td>
<td>83%</td>
<td>17%</td>
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<tr>
<td>HDPE</td>
<td>80%</td>
<td>20%</td>
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<tr>
<td>PET</td>
<td>79%</td>
<td>21%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Potential products</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe fittings, window fittings</td>
<td>Industrial and outdoor products, for example outdoor furniture, bollards, fence posts, decking boards, and railway sleepers. Pellets can be used for packaging.</td>
</tr>
<tr>
<td>Clothing fibres, food containers</td>
<td>If processed via chemical/feedstock recycling, post-consumer plastic can be used as a direct substitute to virgin plastic.</td>
</tr>
<tr>
<td>Limited packaging use</td>
<td></td>
</tr>
<tr>
<td>Bin liners, plastic furniture</td>
<td></td>
</tr>
<tr>
<td>Milk bottles</td>
<td></td>
</tr>
<tr>
<td>Drink bottles, textiles</td>
<td></td>
</tr>
</tbody>
</table>

Appendix D

Technology Readiness Level and Commercial Readiness Index

The Technology Readiness Level (TRL) index is a globally accepted benchmarking tool for tracking progress and supporting development of a specific technology through the technology development chain, from blue sky research (TRL1) to actual system demonstration over the full range of expected conditions (TRL9). It is used across a wide range of sectors.68

By contrast, the CRI moves beyond the proof-of-function measured by the TRL towards an evaluation of the commercial readiness. It assesses overall market maturity of a technology, by reviewing the level of commercial uncertainty and risk remaining in the demonstration and deployment phases, after the technology has been proven.

![Technology Readiness Level and Commercial Readiness Index Diagram]

Source: ARENA, 2014.
