WEALTH FROM WASTE

# GLOBAL SYSTEMS FOR INDUSTRIAL ECOLOGY AND RECYCLING OF METALS IN AUSTRALIA

RESEARCH REPORT

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# BACKGROUND

'Wealth from Waste Cluster' is a major 3-year (2013-2016) research collaboration that aims to identify economically viable options for the recycling of metals from existing products in Australia. It focuses on 'mining' above ground resources, namely metals contained in collections of discarded manufactured products and consumer goods.

The research is examining and quantifying the feasibility of new pathways to access the potential resource base through recycling and identifying the conditions under which such models might be viable for Australia. While technological solutions form an important part of this progress, progress towards a resource efficient circular economy requires more than technological solutions alone. Understanding what other factors – including the operation of collection systems, legislative constraints and market drivers – are required to underpin recycling economics and this is a key focus of the Cluster.

Teams drawn from the different universities and disciplines are undertaking four distinct, but interconnected, research programs to develop a better understanding of this complex landscape and possible pathways for change.

There are four research program streams:

- Program 1: Recycling systems: barriers and enablers for industrial ecology in Australia
- Program 2: Future resource value: characterising stocks and mapping impacts
- Program 3: Developing business models for future value chains
- Program 4: Transition pathways for leadership in resource stewardship

The University of Queensland's Centre for Social Responsibility in Mining leads Program 1 "Recycling Systems: Barriers and Opportunities for Industrial Ecology in Australia". The overall cluster project is led by the University of Technology, Sydney, and also includes Swinburne University of Technology, Monash University and the Center for Industrial Ecology at Yale University, along with an International Reference Panel of experts and CSIRO.

# ABSTRACT

Australia needs to balance its interest in raw materials exports with Australian leadership in stewardship to ensure a resource efficient economy across the entire value chain, e.g. from metals extraction, processing and manufacturing, to product use, and recycling at the end of product life. Achieving this balance will offer the potential to expand the resource base – to be both a primary and secondary, build new niche manufacturing and services companies based on recycling and re-use, and contribute to Australia's transition to a circular type economy.

Industrial ecology is a well-recognised approach to increase resource efficiency and minimise environmental impacts associated with industrial and consumer activities. Its application to metals circulation in the economy provides a system perspective, highlights linkages along the value chain and between supplier networks, helps to analyse both technical and non-technical barriers and opportunities, and suggests solutions to overcome existing challenges.

This report aims to understand the current knowledge of industrial ecology systems globally and utilise this knowledge to identify the potential pathways for enhancing metals recycling rates in Australia.

The key findings are:

- Both at a global level and in Australia, there are a broad range of factors and local influences involved in the successful application and implementation of industrial ecology beyond technical re-use solutions.
- There is an estimated worth of more than AUD6 billion per year if waste metals were fully recovered.
- Assuming existing recovery rates, the estimated potential (lost opportunity) for "wealth from (metal) waste" is of the order of AUD2 billion a year.
- A metal flow analysis of the Australian economy identified that the recovery of metals from waste streams could cover 50% of annual metal consumption in the country, however approximately half the scrap metal collected in Australia is currently being transported overseas.

This report will be of interest to a wide audience in Australia and overseas, including government policy makers, primary and secondary metal processors and recyclers, academic researchers in this area, non-government organisations and community groups interested in enhancing waste reuse and recycling.

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# 1 INTRODUCTION

Australia's rich stocks of mineral resources have traditionally been the source of national wealth and competitive advantage. The security of this wealth is not necessarily guaranteed into the future and therefore alternative sources of resources need to be sought. What were once considered waste materials are now becoming accessible and valuable as 'above-ground' mineral resources. Globally there is growing capacity and innovation in recycling, closed-loop supply chains.

This increase in recycling, closed-loop supply chains is driven by a number of factors, such as the fact that recycling or secondary production of metals has in general a significantly lower energy footprint compared with producing metals from virgin ores. This results in minimising environmental impacts and supporting sustainable development through the efficient use of resources. Other factors include the lack of available natural resources in certain countries, such as those in the European Union and Japan where the closed loop economy model is actively promoted. However, the world demand for metals is still mostly covered by primary production. In the export-oriented resources rich countries such as Australia, it is uncertain how metal-recycling efforts can contribute to a greener economy allowing for continuing economic growth and preserving a country's natural resources.

Australia needs to balance its interest in raw materials exports with Australian leadership in stewardship, which is consistent with a resource efficient economy across the entire value chain. Achieving this balance will offer the potential to expand the resource base available to Australian operations and build new niche manufacturing and services companies based on recycling and re-use. Realising this potential requires an ability to analyse, explore, and conceptualise new business models and understand the linkages along the value chain and between supplier networks.

This report presents the initial outcomes from Program 1 of the Wealth from Waste Cluster. It focuses on understanding the current knowledge of industrial ecology systems globally and utilising this knowledge to identify the potential pathways for enhancing metals recycling rates in Australia to move closer to a circular metals economy. The main objective of this initial investigation is to estimate the potential value of metal recycling and the metals flows in to, around and out of the Australian economy.

This report will be of interest to a wide audience in Australia and overseas, including government policy makers, primary and secondary metal processors and recyclers, academic researchers in this area, non-government organisations and community groups interested in enhancing waste reuse and recycling.

# 2 INDUSTRIAL ECOLOGY APPROACH

## 2.1 SECTION OBJECTIVE

The objective of this section is to present a concise overview of industrial ecology both globally and within Australia to establish how current thinking in this field could shape the research agenda and activities in Program 1 of the Wealth from Waste Cluster "Recycling systems: barriers and enablers for industrial ecology in Australia".

This section is a summarised version of the following journal publication "Corder, G.D., Golev, A., Fyfe, J. and King, S. 'The Status of Industrial Ecology in Australia: Barriers and Enablers' Resources 2014, 3, 340-361." which was part of a Special Wealth from Waste Edition in the on-line journal, *Resources*.

## 2.2 INDUSTRIAL ECOLOGY AND WEALTH FROM WASTE

Australia's unique geographic location as a continent, with long distances between major cities and industrial centres in regional areas, presents challenges from an industrial ecology perspective. On the other hand, however, these challenges can present particular opportunities to adopt innovative approaches to deliver successful outcomes.

Industrial ecology term is commonly accredited to Frosch and Gallopoulos in 1989 (Frosch and Gallopoulos, 1989); the concept itself, however, has arguably been in existence for much longer. Using nature as a metaphor, and aiming to optimise the total material cycle from virgin material to product and to ultimate disposal, industrial ecology closely examines the opportunities to reuse and recycle different waste streams arising in industrial and consumer activities, as well as reorganising the industrial systems to ensure resource efficiency and resilience (Figure 1). In a wider sense it can be even seen as "the means by which humanity can deliberately and rationally approach a desirable carrying capacity, given continued economic, cultural, and technological evolution" (Graedel and Allenby, 1995). It also supports sustainable development through the efficient use of resources, minimising environmental impact while supporting economic success.

Recent research outcomes in industrial ecology and the related sub-field of industrial symbiosis emphasise the development and progression of the thinking in this field and the impact this has had on the successful implementation of initiatives. For instance, China has developed since the early part of this century the largest national Eco-industrial Park (EIP) network, involving 15 national demonstration EIPs and 45 national trial EIPs. The China National Demonstration Eco-industrial Park Program has a number of distinct characteristics—such as the expansion from a single regulator to joint leadership across government departments and the cultivation of hundreds of researchers and professionals working in the field of EIP planning and consultancy—which have contributed to the success of the Program (Shi et al., 2012). In Europe, the Resource Efficiency Flagship Initiative and the subsequent Roadmap for a Resource Efficient Europe have recommended that opportunities to exploit resource efficiency gains through industrial symbiosis should be a priority for members in the European Union (Laybourn and Lombardi, 2012). In addition, the UK's National Industrial Symbiosis Programme (NISP) has been cited as a best practice exemplar of "concrete action" and ought to be replicated across European Union member states (Laybourn and Lombardi, 2012).

Thinking has now moved to the stage of developing a theory towards industrial symbiosis (Chertow and Ehrenfeld, 2012) as well as an evolution in the definition of industrial symbiosis focusing on eco-innovation and establishing sustaining cultural change (Lombardi and Laybourn, 2012). This is supported by the extensive review of industrial symbiosis literature which illustrates over a 15 year period from 1997 that the topic has evolved from practice oriented, based on the experience and observation to a more systematic and diverse set of topics in theory building and worldwide practical implementation (Yu et al., 2014).

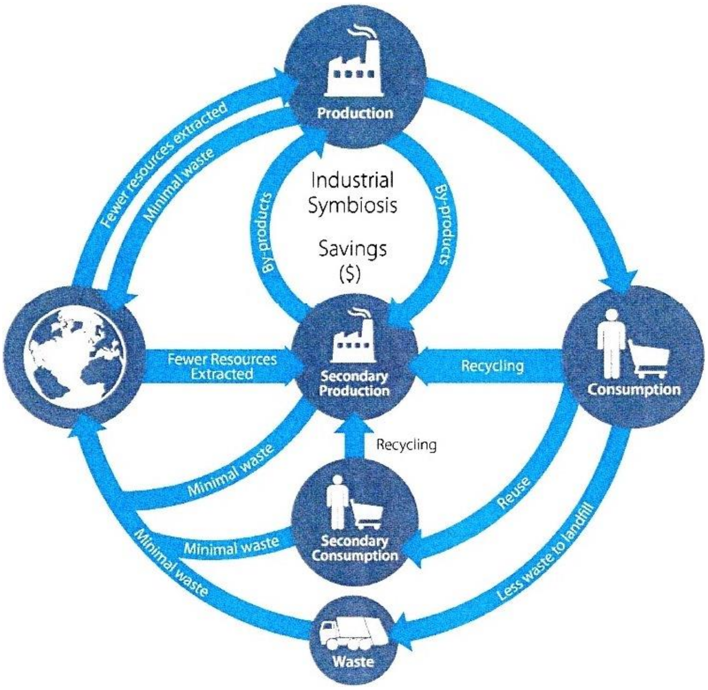



**Figure 1:** Industrial ecology process (EPA, 2013).

While industrial ecology can take on a product-based systems perspective or a geographically defined local–regional industrial ecosystem approach (Korhonen, 2002), the focus of 'Wealth from Waste' is on a specific material stream – metals, mainly in the metallic form (Figure 2). Due to their nature, metals can be infinitely reused without losing their physical properties. The range of targeted elements varies from metals used in the economy in high volumes such as for example iron and steel, aluminium, and copper, to critical and precious metals usually used in minor quantities, e.g. gold, platinum group metals (PGMs), and rare earths.

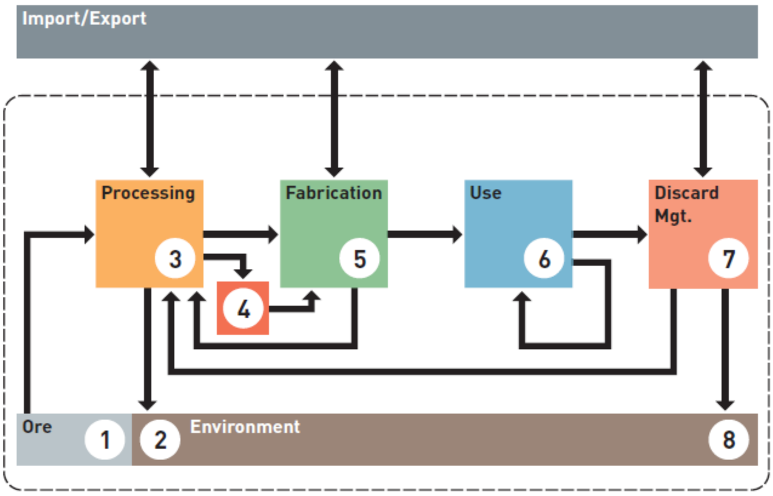



**Figure 2:** The generic life cycle of a metal, with stock locations indicated: 1- metal in virgin ore bodies; 2- metal in tailings; 3- metal in processor stockpiles; 4- metal in government stockpiles; 5- metal in

manufacturer stockpiles; 6- metal in-use stock; 7- metal in recycler stockpiles; 8- metal in landfill stockpiles. Source: (UNEP, 2010).

## 2.3 INDUSTRIAL ECOLOGY IN AUSTRALIA

Application of industrial ecology in Australia has been demonstrated with a few heavy industrial regions studies, several mixed industrial parks and waste exchange initiatives, as well as with investigations of reuse options for specific waste flows. The level of success, significance of achievements, and detailed reporting greatly varies between different cases. The most well documented and cited examples relate to the regional resource synergies studies, or industrial symbiosis, in such heavy industrial areas as Kwinana in Western Australia, and Gladstone in Queensland. Both are highly developed heavy industrial areas, including alumina, nickel, oil, iron, cement, and pigment industries.

The early history of applying the concept of industrial ecology in Australia is closely related to cleaner production techniques, eco-efficiency and waste management practices. The combined efforts of the state and federal government, industry associations, academic institutions and environmental organisations in mid-1990s resulted in the successful demonstration of these approaches to minimise environmental impacts arising from industrial activities within different sectors, and in recommending the development of national guidelines for companies based on this experience (Dames and Moore, 1997, Dempster et al., 1997, ANZECC, 1998).

Further application and promotion of industrial ecology approaches has been attributed to several initiatives supported by the Australian government, such as Green Stamp Program (van Berkel, 2007), Centre for Sustainable Resource Processing (van Beers et al., 2007b), and others. Some of this work resulted in the development of new frameworks that could be used elsewhere, and help to replicate and to enhance successful applications of industrial ecology (van Beers et al., 2007a, Golev and Corder, 2012). More recently, the 2013 New South Wales (NSW) Government Waste and Resource Recovery Initiative has recognised the potential of industrial ecology by prioritising the establishment of four industrial ecology networks as part of its Business Recycling Program (NSW Government, 2013). This industrial ecology initiative is driven from the success of the NSW Sustainability Advantage program, which supports businesses to reduce risk and cost by reducing their environmental impact. This includes identifying and implementing industrial symbiosis opportunities. The program has resulted in 530 businesses reducing costs by AUD75 million a year due to reductions of energy, water, waste and raw materials (NSW Government, 2013). The support of industrial ecology or symbiosis within government marks a strategic turning point in waste management, recognising waste as a potential resource. It supports both environmental goals to reduce waste to landfill and industry goals to improve resource efficiency and competitiveness.

In addition, the Waste Management Association of Australia (WMAA), the peak waste industry body established in 1991, actively promotes waste reuse and recycling practices within small and medium enterprises (SMEs). WMAA also supports the Australasian Industrial Ecology Network (AIEN). The AIEN has active industry networks in New South Wales and Victoria and led the organisation of the Australasian Industrial Ecology conferences over the last five years. In June 2013, the AIEN and Enterprise Connect were involved in organising a meeting of industrial ecology stakeholders. This included government representatives from NSW, Victoria and South Australia sharing their experiences in implementing industrial ecology and symbiosis in their respective regions and discussing opportunities for Australia. This was the first meeting of its kind in Australia and representative agencies, while interested to understand the potential benefits of industrial ecology with a view to supporting its uptake, lacked a common approach to implementing programs or strategies to increase the adoption of industrial ecology, in all its forms, for Australia (Ferrari, 2013).

## 2.4 BARRIERS AND ENABLERS FOR INDUSTRIAL ECOLOGY

A range of barriers and enablers to industrial ecology development have been addressed in literature, including the role of government environmental policies, planning policy, management practices within the industries, and a lack of specific tools to organise and stimulate the inter-industry collaboration (van Beers et al., 2007a, Golev et al., In press, Brand and de Bruijn, 1999, BCSD-GM, 1997, Heeres et al., 2004, Fichtner et al., 2005, Mangan and Olivetti, 2010, Harris, 2004). Some studies also identified the triggers that are specific events to help overcome barriers or activate enablers for the realisation of synergy projects. For example, the motivational barriers can be targeted by the setting of a stimulator/initiator for the project, establishment of a coordinating institution, or by the regional industry champion who takes the responsibility for industrial ecology development. Information sharing and trust between industries can be improved with the presence of a regional "information office" on existing wastes and their reuse opportunities, and special workshops involving representatives of different regional companies (van Beers et al., 2007a, Brand and de Bruijn, 1999, Corder, 2008). An example of barriers and enablers is presented in **Table 1**.

**Table 1.** An example of barriers and enablers to industrial ecology. *Source: (van Beers et al., 2007a).*

| Category | Drivers | Barriers | Triggers |
|---|---|---|---|
| Economics | Increased revenue through lower operational costs.<br>Reduced risks and liability | Relatively low price for utility resources.<br>Relatively low costs for waste disposal | Secure availability and access to vital process resources |
| Information availability | Local industry organisation.<br>Staff mobility | Confidentiality and commercial issues | Local and regional studies |
| Corporate citizenship and business strategy | Corporate sustainability focus.<br>Community engagement and perception | Core business focus.<br>Community engagement and perception | Industry champion |
| Region-specific issues | New company entering industrial area.<br>Geographic isolation | Distance between companies | Major new project developments |
| Regulation | Existing environmental regulations (e.g., air and water quality requirements and reporting) | Existing environmental regulations (intensive approval procedure for by-product reuse).<br>Existing water and energy utility regulations | New pollutant targeted regulations (e.g., carbon tax and mandatory energy audits) |
| Technical issues | Research and technology developments.<br>Technical obsolescence of existing process equipment | Availability of (reliable) recovery technologies | Major brownfield development within company |

While synergy connections and recycling initiatives have to provide a sound business case, most industries also agree that financial benefits are not the only driver, and such aspects as supply risks, access to vital resources, environmental regulation, and community relations are also important for proceeding with the project (van Beers et al., 2007a). Balancing financial objectives against sustainability benefits of industrial ecology applications presents a challenge when proposed initiatives have moderate or low financial benefits but have high or possibly moderate sustainability benefits (Corder, 2008).

The barriers to industrial ecology can be examined at different levels of its applications, including heavy industrial areas, mixed industrial parks, and waste exchange networks (Corder et al., 2014). The generation, collection, and initial processing of scrap metal, however, are mainly represented by small and medium enterprises (SMEs). Constituting the bulk of businesses operating in Australia, and making significant contributions to the broader commercial and industrial (C&I) waste stream, SMEs also face some specific challenges in applying industrial ecology to their practices.

A disposal-based survey of C&I waste in Sydney, Australia conducted in 2008 found that SMEs produced 45% of the total C&I waste load, a larger fraction than the next six largest sectors combined, including manufacturing (DECCW, 2010). Statewide SME waste generation rates reported for Victoria, Western Australia and South Australia are lower, but still significant at 19%, 37% and 19%, respectively. Despite the large aggregate waste quantities SMEs produce, they have difficulty engaging recycling collection as their individual recyclate (raw material sent to, and processed in, a waste recycling plant) loads are too small to make the provision of a service viable (Bremner et al., 2013).

Clearly there are gains to be made through engaging SMEs in industrial ecology; however a fundamental issue faced by SMEs, particularly amongst smaller businesses, is the often unavoidable need to de-prioritise waste management (unless costs become very high) and sustainability-related activities in the face of time, resource and know-how constraints, and financial and competitive risks (Holt et al., 2000, Petts et al., 1999). Thus even when SME management have an interest in sustainability, they require encouragement and assistance to undertake initiatives beyond their day-to-day activities and embrace opportunities presented by industrial ecology, because to many, the business case for undertaking sustainability measures, including industrial ecology activities, has yet to be made.

In Australia, the development of the WasteNot Resource Exchange, described by Fyfe *et al.* (2011), involved close engagement with over 40 local SMEs through workshops staged to inform the design of the web application and the identification of industrial symbiosis opportunities. As with the experience of Peters and Turner (2007) experience, waste exchange opportunities were readily identified in what were essentially facilitated networking opportunities. The key enablers for SME participation in this form of industrial ecology identified by the businesses included its potential to reduce cost of engaging waste contractors and provide cost-effective environmental inputs into processes, and the general perception of it being good for the environment. Importantly, the fact that the proposed exchange was locally oriented and historically grounded (the Duck River Catchment within which the waste exchange program was based has a long history as a unique industrial precinct in the region) was viewed as an important driver to participation in the initiative (Fyfe et al., 2009). Peters and Turner (2007) also noted the importance of geographical context, with businesses located within village areas more inclined to improve welfare and amenity of the local community, in contrast to businesses in dedicated industrial parks that were more interested in cost savings and efficiency gains.

Another critical barrier for SMEs is the lack of physical space to stockpile outgoing or incoming waste materials. A face-to-face survey of 12% of SMES in the city of Hobart, Australia by Parsons and Kriwoken (Parsons and Kriwoken, 2009) found “inadequate storage space” to be a primary barrier to participation in conventional recycling. Space constraints were also a common issue for SMEs participating in the development of WasteNot, especially amongst SMEs having to maintain stringent hygiene standards for food production (Fyfe et al., 2010).

As current research thinking in industrial ecology highlights, there are many local variables, parameters and actors involved in the successful application and implementation of the concepts of industrial ecology beyond technical re-use solutions. Without any significant, ongoing and successful examples of industrial ecology, Australia continues to lag behind international efforts.

Answers to the following questions could greatly help enhancing industrial ecology applications in Australia:

- How would better information availability, including detailed reporting on economic and environmental achievements from implementing synergy projects assist uptake of industrial ecology applications?
- Would recognition and active promotion of national champions in industrial ecology, for advertising and sharing best practices and experience increase uptake?
- What further improvements in the environmental regulation could contribute and encourage the adoption of best-known technologies and waste reuse projects?
- Would defining of long term targets for waste reuse and recycling, supported by the development of specific projects drive better industrial ecology outcomes?
- Could sharing of common failures and successful factors between local and State government efforts across Australia expand the collective knowledge base and increase support and acceptance of industrial ecology applications?

# 3 AUSTRALIAN CONTEXT: METALS PRODUCTION, CONSUMPTION AND RECYCLING

## 3.1 SECTION OBJECTIVE

The objective of this section is to establish the potential monetary value for metals recycling of end of life products in the current Australian context. This analysis provides an estimation of the potential magnitude of the market for new metals recycling initiatives in Australia.

## 3.2 PRIMARY METAL MINING AND PROCESSING

The Australian economy has relied on mining for successive generations. The abundance of natural resources and the relatively low population has predetermined the role of Australian economy on the global market as a resources supplier. The exported mineral resources can be subdivided into energy related (coal, oil, natural gas, uranium), metal related (e.g. iron ore, alumina), and others (e.g. gems) – see Figure 3.

Metals and metal concentrates currently deliver the country's main resources export revenue (58% in 2012/13), followed by energy resources such as coal, natural gas and uranium (38%). More than 90% of minerals mined in Australia are directly exported; for metals and metal concentrates this figure is close to 98%.

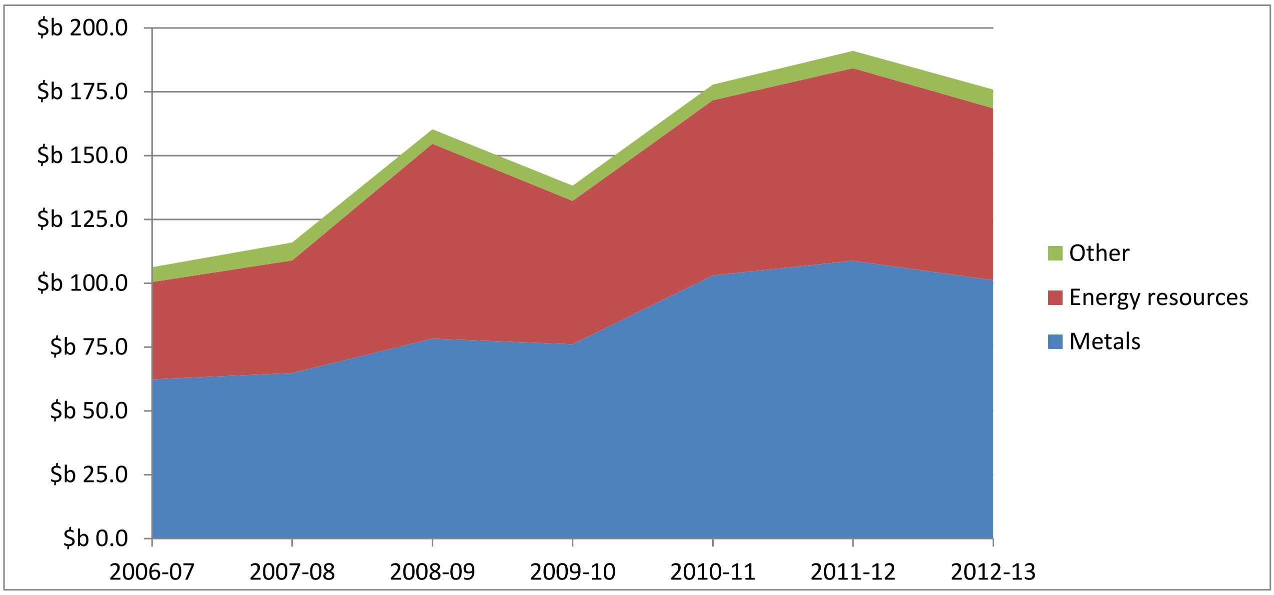
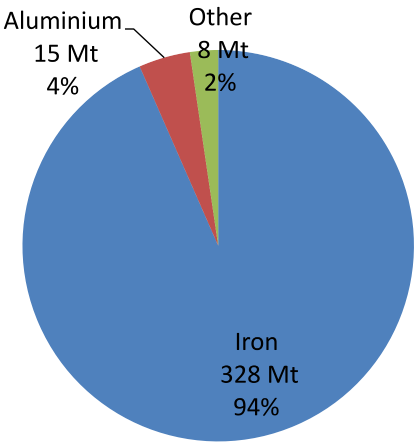
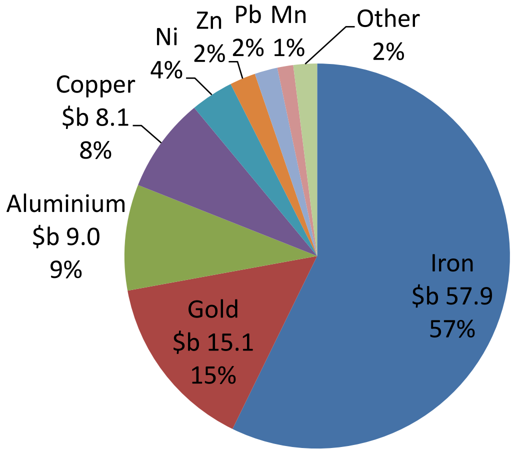



**Figure 3:** Australian mineral resources export revenue. *Source: (BREE, 2013).*

In 2012-13, Australia exported more than 570 million tonnes of metallic content materials (contained more than 300 million tonnes of extractable metals – refer to Figure 4). At the same time, the apparent domestic consumption of metals was about six million tonnes (BREE, 2013). Some metals are primarily exported as concentrates (e.g. iron ore, alumina, copper, zinc, lead, manganese), while others in the form of refined metals (e.g. nickel, gold, silver) or chemicals (e.g. titanium dioxide pigment).



a)



b)

**Figure 4:** Australian metal concentrates and refined metals exports in 2012/13: a) by weight (100% metal content), b) by monetary value. *Source: (BREE, 2013).*

The metals and metal concentrates production in Australia is more than 99% represented by five elements – iron, aluminium, copper, zinc, and manganese (BREE, 2013). Australia is the world largest producer of iron ore and bauxite, covering more than 20% of world needs in minerals to produce steel and aluminium (BREE, 2013, USGS, 2014); leading producer of titanium, and zirconium concentrates; and among top five countries in the production of copper, zinc, manganese, nickel, and gold (USGS, 2014).

While the overall production and export of metal concentrates in Australia has increased over the last decade, the production of refined metals declined, mainly due to the decrease in steel output (**Table 2**). On per capita basis, the figure dropped from 545 kg in 2006/07 to 349 kg in 2012/13.

**Table 2.** Refined metals production in Australia. *Source: (BREE, 2013).*

| Year | Selected metals, thousand tonnes | | | | | | Total for selected metals | Per capita, kg |
|---|---|---|---|---|---|---|---|---|
| | Raw steel | Al | Cu | Zn | Pb | Ni | | |
| 2006-07 | 8010 | 1954 | 435 | 502 | 224 | 118 | 11242 | 545 |
| 2007-08 | 8151 | 1964 | 444 | 513 | 242 | 121 | 11436 | 546 |
| 2008-09 | 5568 | 1974 | 499 | 512 | 251 | 111 | 8915 | 419 |
| 2009-10 | 6886 | 1920 | 395 | 521 | 218 | 120 | 10062 | 462 |
| 2010-11 | 7305 | 1938 | 485 | 505 | 226 | 101 | 10560 | 479 |
| 2011-12 | 5383 | 1938 | 486 | 511 | 216 | 122 | 8655 | 388 |
| 2012-13 | 4850 | 1788 | 454 | 502 | 199 | 135 | 7928 | 349 |

## 3.3 ESTIMATION OF METALS CONSUMPTION

The metal production and direct shipments are usually well recorded through national and international statistics allowing for estimation of the apparent consumption of major metals (**Table 3**). The true metal consumption, however, may be significantly higher or lower than the apparent consumption. True consumption takes into account all indirect import and export flows, where metals are associated with fabricated and manufactured goods, e.g. preassembled construction structures, machinery, vehicles, and consumer products. The true metal consumption and in-use stocks are not easy to estimate, it requires additional investigation, and often relies on multiple assumptions and expert opinion.

**Table 3.** Apparent (industrial) consumption for selected metals in Australia. *Source: (BREE, 2013).*

| Year | Selected metals, thousand tonnes | | | | | Total for selected metals | Per capita, kg |
|---|---|---|---|---|---|---|---|
| | Iron and steel | Al | Cu | Zn | Pb | | |
| 2006-07 | 7679.6 | 330.8 | 144.0 | 86.7 | 25.6 | 8266.6 | 401 |
| 2007-08 | 7868.0 | 314.1 | 153.0 | 84.9 | 24.9 | 8444.9 | 403 |
| 2008-09 | 5908.5 | 225.1 | 141.0 | 70.9 | 21.0 | 6366.6 | 299 |
| 2009-10 | 7073.1 | 294.4 | 131.0 | 70.6 | 20.6 | 7589.7 | 348 |
| 2010-11 | 7388.2 | 251.6 | 142.0 | 64.7 | 28.1 | 7874.6 | 357 |
| 2011-12 | 6038.3 | 234.6 | 111.0 | 55.1 | 19.7 | 6458.7 | 289 |
| 2012-13 | 5534.4 | 219.7 | 91.0 | 72.6 | 22.8 | 5940.6 | 262 |

The number of detailed investigations for metal flows and in-use stocks is relatively limited worldwide (Pauliuk et al., 2013, UNEP, 2010, Chen and Graedel, 2012). Some data on iron and steel, and aluminium flows can be obtained from international reports, e.g. of World Steel Association (Worldsteel, 2013) and International Aluminium Institute (www.world-aluminium.org). World historic flows of selected technological metals were also investigated in Yale stocks and flows (STAF) project (e.g. Chen and Graedel, 2012). In Australia, the only detailed study on metal flows in the economy was performed for copper and zinc (van Beers et al., 2007c). A related study characterised the in-use stocks of copper and zinc at a variety of spatial levels - central city, urban region, states/territories, and country - in the Australian economy (van Beers and Graedel, 2007).

Indirect import and export of iron and steel is estimated by Worldsteel Association. For Australia, net indirect imports (i.e. import minus export) steadily grew over the last decade: from 1420 kt in 2002 to 4670 kt in 2011 (**Table 4**). The same trend can be likely applied to indirect imports and exports for other metals.

**Table 4.** Australian indirect export and import of steel. *Source: (Worldsteel, 2013).*

| Year | Steel in products (metal content), thousand tonnes | | Net indirect import (import minus export) | Per capita, kg |
|---|---|---|---|---|
| | Indirect export | Indirect import | | |
| 2002 | 646 | 2066 | 1420 | 72 |
| 2003 | 600 | 2475 | 1875 | 94 |
| 2004 | 603 | 2865 | 2262 | 113 |
| 2005 | 957 | 4396 | 3439 | 169 |
| 2006 | 679 | 3790 | 3111 | 151 |
| 2007 | 683 | 4095 | 3412 | 163 |
| 2008 | 697 | 4576 | 3879 | 182 |
| 2009 | 537 | 3312 | 2775 | 127 |
| 2010 | 667 | 4223 | 3556 | 161 |
| 2011 | 683 | 5354 | 4671 | 209 |

We have assumed that all indirect import and export flows add in a total of up to six million tonnes to metal consumption in Australia in 2012/13. This results in a metal consumption rate of about 12 million tonnes a year (2012/13), or about 520 kg per capita. This figure is higher than 300 to 400 kg per capita estimation for EU-27 countries and the USA, and about 250 kg world average (Rogich and Matos, 2008, USGS, 2014). However, this estimate of 520 kg per capita for Australia aligns well with such countries as Sweden and Norway, and is below Canada and fast-growing Asian economies like Singapore, Taiwan, and South Korea (Worldsteel, 2013).

## 3.4 METALS IN THE WASTE STREAMS AND RECYCLING RATES

The Australian economy is one of fast growing among developed countries, allowing for higher individual incomes, consumption rates, and the overall standard of living. This also means a higher level of urban stocks and waste generation, representing good potential for recycling and transition to a circular type economy.

The energy requirements and carbon footprint for most recycled metals is 50% to 99% lower compared with primary produced metals, e.g. ferrous metals (58%), aluminium (92%), copper (65%), nickel (90%), zinc (76%), lead and tin (99%) (Grimes et al., 2008). “On average, the metal stocks used in more-developed countries equate to between ten and fifteen metric tonnes per citizen. Of this amount, five metals – iron, aluminium, copper, zinc, and manganese – make up more than 98%” (UNEP, 2013). The combination of these two statements represents a strong incentive for promoting the recycling of metals.

The world demand for metals is predominantly covered by primary production. Only three metals (niobium, lead, and ruthenium) have more than 50% recycled content, and another 16 metals are in the 25% to 50% range (Graedel et al., 2011). A critically important question, however, is how much of metal content in the end-of-life products is actually recycled, and how much is lost in the landfills. The existing estimations show that for 18 metals the recycling rate is above 50%, and for another six metals it is in between 11% and 50% (Figure 5), while many other metals mostly end up in the landfills (Graedel et al., 2011).

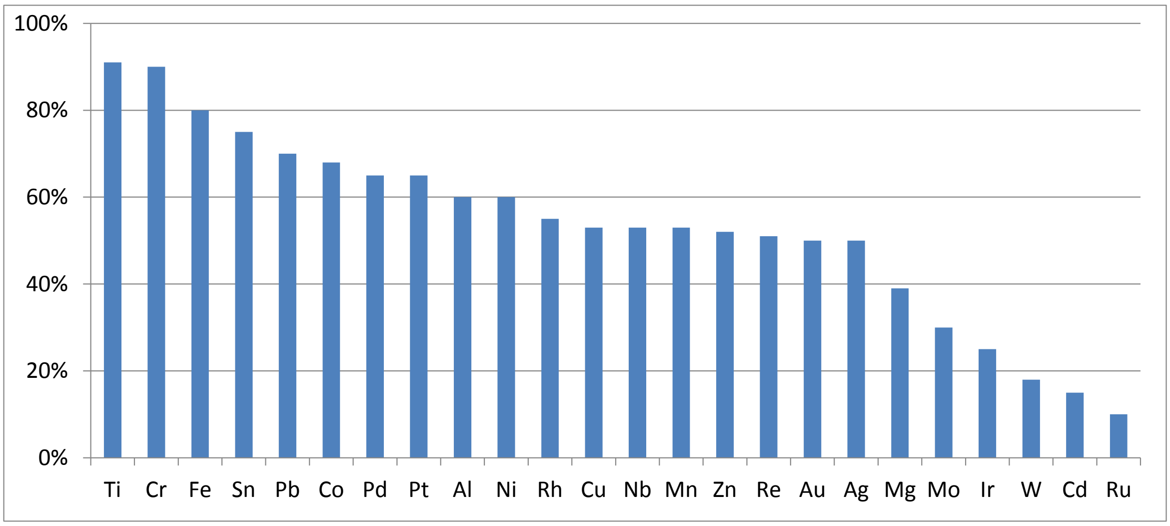



**Figure 5:** World estimates for end-of-life recycling rates (EoL-RR). *Source: (UNEP, 2011).*

The recycling of metals includes several main stages such as collection, sorting, shredding, physical separation, hydrometallurgical treatment, and smelting. Metal recycling usually involves multiple companies at different stages, the number of recovered metals and level of recovery significantly depends on the waste stream and processing technology. The main challenge with improving recycling rates is that “the complexity of consumer product mineralogy requires an industrial ecological network of many metallurgical production infrastructure to maximise recovery of all elements in end-of-life products” (UNEP, 2013).

Based on reports from UNEP and USGS we have estimated that the annual waste metal generation level could account for 50-60% of the current consumption (taking into account the average period of metal use within the economy, metal consumption and population growth over the last few decades). For Australia, this results in about 300 kg per person or seven million tonnes in total of metals in the waste streams a year – refer to Figure 6. This figure is higher than data derived from national waste reporting, i.e. 252 kg per person or 5.6 million tonnes in total of metal scrap in the accounted waste streams in 2011/12 (Randell et al., 2014). The latter, however, does not include a certain metal loss in obsolete (degraded) stocks and a loss during the collection and processing, neither differentiate old scrap (from end-of-life products) and new scrap (waste metal and rejects from new manufacturing).

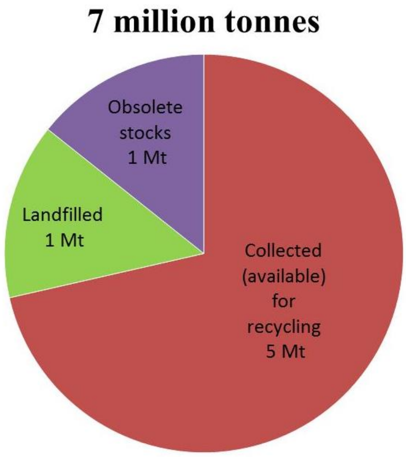



**Figure 6:** Destination of metals in waste streams in Australia (2012/13). *Source: Authors estimation.*

The waste streams outline the potential value for metal recycling, apart from metals in the obsolete stocks, which are usually fully lost for recovery. Based on the figures above there is an estimated worth of more than AUD6 billion if the waste metals were fully recovered (2012/13 metals price level) – refer to Figure 7. The estimated potential for "wealth from (metal) waste" in Australia is of the order of AUD2 billion a year, consisted of the value lost with landfilled metals and lost opportunities in domestic processing of collected metal scrap. Currently, only about half of collected waste metal is processed in Australia. There are no domestic facilities for separation and smelting non-ferrous scrap (apart from secondary aluminium and lead production); and most of it is shipped to and processed in Asia. The only well-established metal recycling system in the country is for iron and steel scrap, and this is part of the conventional iron smelting technology.

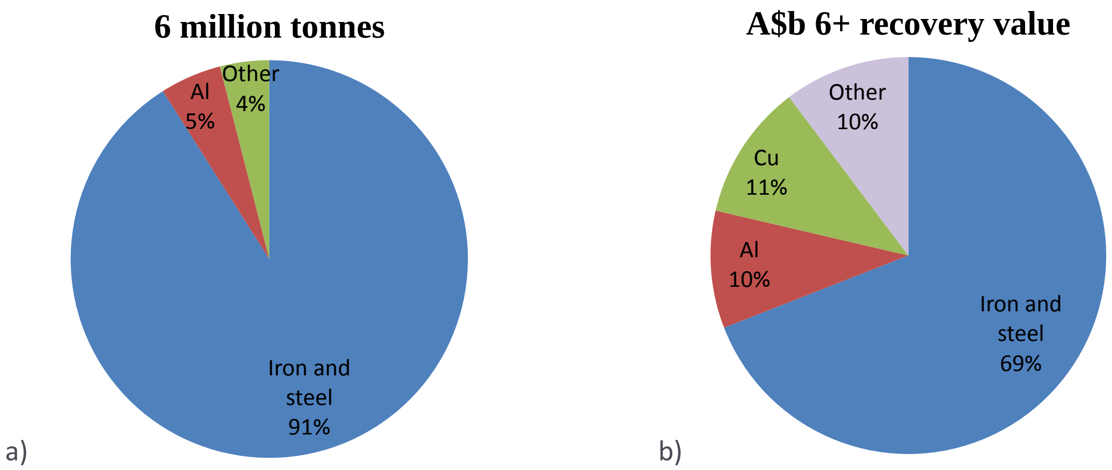



**Figure 7:** Recoverable metals in waste streams in Australia (2012/13): a) by weight (100% metal content), b) by monetary value. Note: the composition of metals in the waste streams is based on the Center for Industrial Ecology STAF project data for Australia (Center for Industrial Ecology, 2014).

# 4 METAL FLOWS IN AUSTRALIAN ECONOMY

## 4.1 SECTION OBJECTIVE

The objective of this section is to estimate the flows of metals in to and out of Australia and establish the current level of metals circularity in the Australian economy.  An important outcome of this analysis is that it estimates the magnitude of metal production, consumption, scrap generation and accumulation of in-use metal stocks in Australia.

## 4.2 METALS FLOWS

The closed loop economy presupposes predominantly cyclical use of metals within the system, yet it is economically impractical to limit the system to the national or regional borders, and it should be justified and achievable at the global scale. This means that some countries, such as Australia, still may need to play the role of net providers of primary (mined) material resources. However, such roles on the international stage should not undermine the need for enhancing the collection, reuse and recycling of materials in the national or domestic borders.

In general terms, the flow of metal in the economy starts from mineral extraction, goes through several stages of transformation (such as processing, refining, fabrication, and manufacturing), includes product use in the economy (consumption), and ends up with product disposal, or recycling of metal for the next cycle. Export and import flows of minerals, refined metals, fabricated and manufactured products also play a significant role in estimating material flows, and often require a separate investigation. Input-output and material flow analysis techniques are usually employed to represent the circulation of specific material in the economy. The simplified model of metal circulation in the economy is presented in Figure 8.

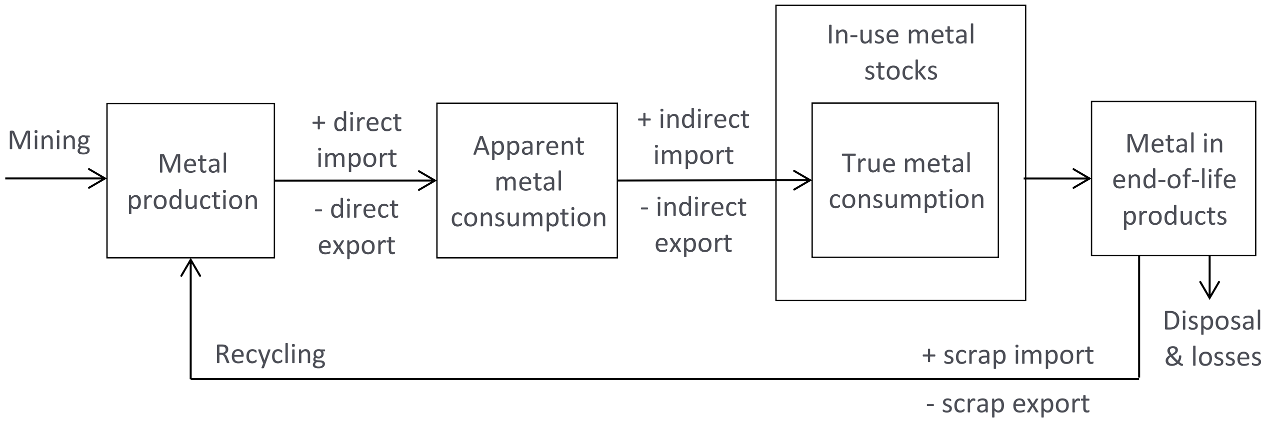



**Figure 8:** Estimation of metal use in the economy.

## 4.3 INPUT-OUTPUT ANALYSIS

The overall inputs and outputs for metals in the Australian economy in this analysis have been calculated based on data and assumptions from Section 3. The overall amount of consumed metals is estimated at 12 million tonnes or about 520 kg per person, the amount of generated scrap and waste metal is six million tonnes or about 260 kg per person, and the obsolete (degraded) stocks are assumed at one million tonnes a year. There is limited information on the type of metal and metal contained products consumed and scrapped in Australia. The detailed investigation for specific metal or commodity cycle in the economy is a very intensive and complex process. However, it is evident that major part of metals is consumed for buildings, infrastructure, machinery, and vehicles, and locked in there for an extended period of time (Figure 9). Consumer products, including different electronic devices, are another important category due to their high annual growth rates, relatively short life cycle, as well as the presence of precious metals.

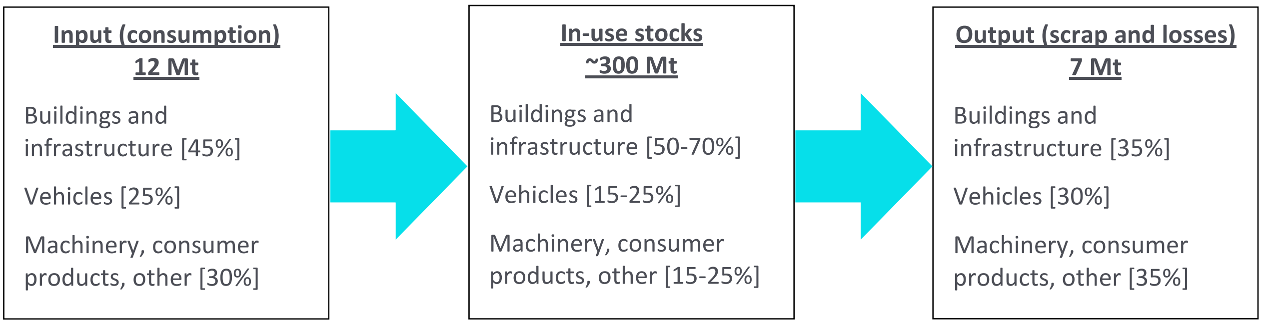



**Figure 9:** Metal inputs and outputs in the Australian economy by major sectors (2012/13). Note: sector split percentages are indicative estimates based on an amalgamation of estimates from various public domain sources.

The existing statistics on waste disposal and recovery in Australia does not allow to directly investigate the origin of material presented in Figure 9. The official classification for waste materials is based on the waste collection system and includes three major groups: municipal solid waste (MSW), commercial and industrial waste (C&I), and construction and demolition waste (C&D). There are also some variations in the reporting system used by municipalities in different states across Australia, as well as there are different reporting requirements for waste processors and metal recyclers. A significant part of the data used for investigating metal flows in the economy still relies on expert assumptions.

The official reported metal collection rates in Australia exceed 90% (Randell et al., 2014), however this does not include a certain metal loss in obsolete (degraded) stocks and a loss during the collection and processing. The real metal end-of-life recycling rate (EoL-RR) is likely below 70%. There are still opportunities for enhancing the collection and recovery, including preventing metal losses at the disposal and stimulating secondary metal production within the country versus importing scrap overseas (Figure 10), including the recovery of precious and-or critical metals from consumer products. This is discussed further, including the key assumptions, in Section 4.4.

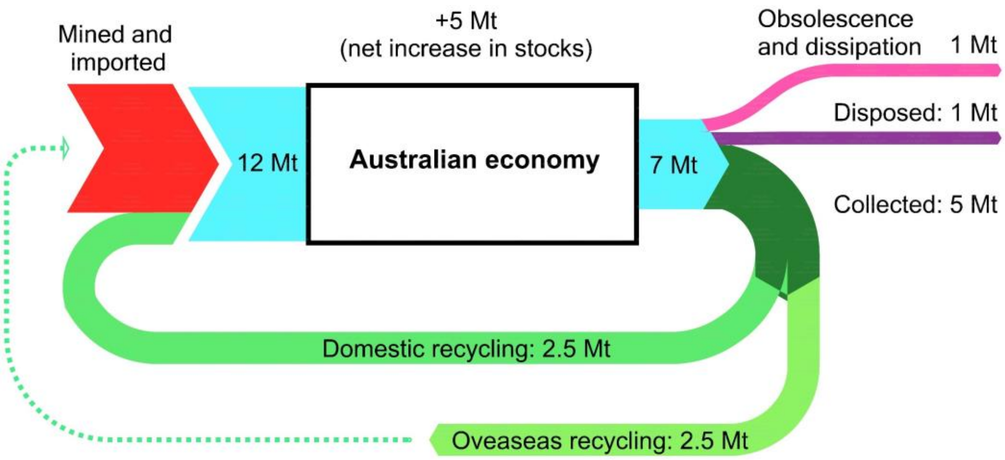



**Figure 10:** Metal inputs and outputs in the Australian economy (2012/13).

## 4.4 METAL FLOWS MODEL

An estimation of material flows in the economy through all main transformation stages – from mining to manufacturing, and accounting for export and import flows allows for a more detailed metal flows model. This model establishes a basis for analysis of metal circulation in the Australian economy, helps to investigate further the barriers and enablers for waste collection and recovery, and to develop recommendations for achieving higher recycling rates in the country (Figure 11).

Some key parameters and assumptions used for modelling metal flows presented in Figure 11 are listed in Table 5. A similar approach can be used to analyse data over several years, as well as for future predictions and scenarios planning. There was a level of uncertainty related to the accuracy of data from some of the reports listed in Table 5. This carried over to the estimates in Figure 11 and highlights the difficulty of obtaining an accurate overview of the flow of metals in wastes and end-of-life products across Australia.

**Table 5.** Key parameters and assumptions used for metal flows modelling.

| Parameter or indicator | Data/estimation (2012/13) | Source of information, and notes |
|---|---|---|
| **Metals mining and processing** | | |
| Mineral concentrates production (net metal content) | ~360 Mt | National statistics (BREE, 2013), and authors assumptions for net metal content if not provided |
| Refined metals production (raw steel, Al, Cu, Zn, Pb, Ni) | 7928 kt | |
| **International trade** | | |
| Metal concentrates export (net metal content) | ~350 Mt | National statistics (BREE, 2013), and authors assumptions for net metal content if not provided |
| Mineral concentrates import (net metal content) | ~88 kt | |
| Refined metals export (iron and steel, Al, Cu, Zn, Ni, Pb) | 3850 kt | |
| Refined metals import (iron and steel, ferroalloys, Al, Mg) | 2016 kt | |
| Fabricated and manufactured products export (net metal content) | ~1000 kt | International statistics (UN Comtrade, 2014), authors assumptions for net metal content and missing weight data |
| Fabricated and manufactured products import (net metal content) | ~7000 kt | |
| Waste metal export | 2539 kt | |
| Waste metal import | 7 kt | |
| **Scrap collection and recycling** | | |
| Waste metal collected | 5096 kt | National environmental reporting (Randell et al., 2014). Note: data for 2011/12; does not include losses in collection and processing |
| Waste metal landfilled | 492 kt | |
| **In-use metal stocks** | | |
| Per capita estimation | 10-15 t | International reports (UNEP, 2010) |
| Total for Australia | ~300 Mt | |

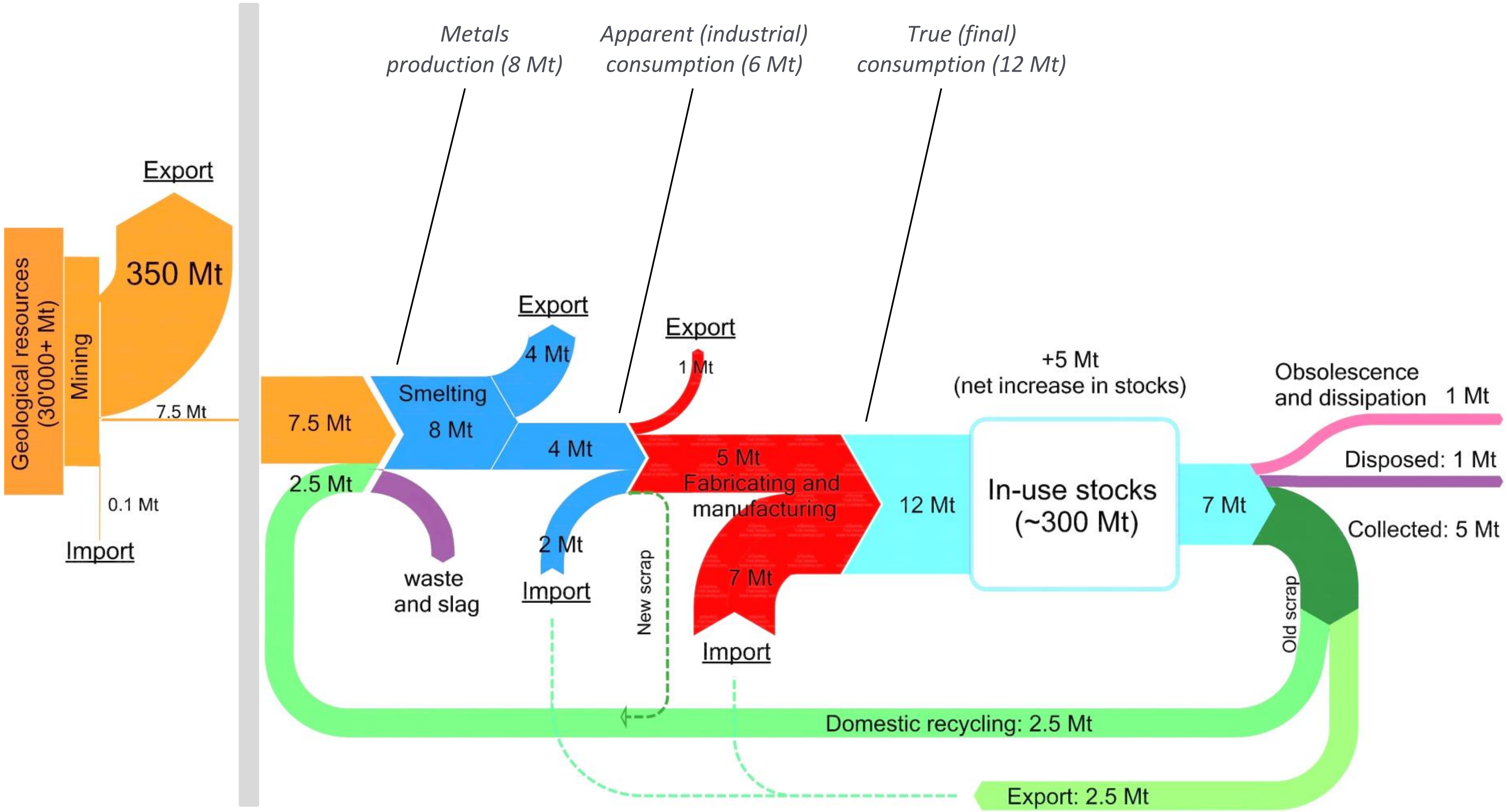



**Figure 11:** Metal flows in Australian economy (2012/13). Note: all figures are estimated for 100% metal content.

# 5 BARRIERS AND OPPORTUNITIES FOR CIRCULAR USE OF METALS IN THE ECONOMY

## 5.1 SECTION OBJECTIVE

The objective of this section is to articulate the current findings, based on the research and analysis that has been presented in previous sections of this report and identified to date in Program 1, for enhancing higher levels of circular use of metals in the Australian economy.

## 5.2 REPORTED FACTORS IN AUSTRALIA

Minimising of waste generation and increasing of recycling rates have been considered as priorities in the environmental regulation in Australia since 1990s. The problem areas and potential for improvement have been also regularly addressed within the national and state reporting system. The latest national report on waste generation and resource recovery (Randell et al., 2014) indicated several key elements in the recycling framework required to achieve higher rates for resources recovery. Significant opportunities remain in the following categories:

- Broad scale landfill disposal bans for untreated or unsorted solid wastes;
- Use of a wide range of resource recovery technologies;
- Comprehensive reporting requirements for waste management;
- Source segregation of solid waste collection (i.e. avoiding mixed loads);
- Hypothecation of levy landfill funds to waste initiatives and recovery infrastructure.

Despite variations between different states in Australia in their waste frameworks and regulation, landfill levies rates, and direct government support, the long-term targets (2020 and beyond) for resource recovery in all states aim to achieve at least 70-80% recovery rates for all waste streams (MSW, C&I, and C&D) versus current average rate of 60%[1] (Randell et al., 2014). While metal recovery targets are not specified, it is likely that they will be set at 90% or higher.

## 5.3 AUSTRALIAN INDUSTRIAL ECOLOGY FORUM

As part of the Wealth from Waste Cluster an Industrial Ecology Forum (workshop) was held in March 2014. The main aims of the workshop was to bring together different stakeholders and share the experiences of existing state of recycling activities in Australia, as well as attempt to identify major potential opportunities and enablers for greater uptake in Australia based on international leading and emerging practices.

The main results from this first workshop of two show that:

[1] There is an ambiguity in defining and use of recycling rates as indicators in the waste management and recycling reports in Australia. In most cases they represent the rate of collected recyclables or waste avoided from disposal; however, not all of the collected materials result in new products due to losses in processing, and there are known cases of waste exported overseas being landfilled instead of recycling. Thus, the actual recycling rates are usually lower.

- Product design is an imperative for circular economy and efficient recycling, however there is a limited influence that Australia can make on imported products. The best option would be to closely follow other countries legislative requirements in this area, e.g. European Union.
- Business models are crucial for successful recycling activities. The main focus should be on innovative systems as well as adopting technologies from other countries.
- A national approach should create grounds for recycling businesses becoming profitable. The market signals have to drive behaviour and investment in the recycling and waste management sector. Stimulus is better than direct regulation (though co-regulation can be desirable in some cases).
- There is a lack of data and understanding on potential lost opportunities, that is unrecovered materials. Additional investigation and mapping of above ground stocks, and material flows are needed.
- Different waste types require different approaches and thus a need to focus on a specific industry and its infrastructure needs/gaps for each waste stream.
- A characterisation of profitability zones (marginal costs of recycling for distances and types of waste) would provide a better understanding on how the national/state regulation influences the efficiency of recycling and may increase/decrease overall recycling rates.

The key findings above speak to the core aims of Program 1 in the Wealth from Waste Cluster and align with many of the points raised in this report. An important question that remains is how to effectively shift the resources paradigm towards circular economy in the context of Australian recycling landscape. This is a crucial part of the future research agenda in this Program of work, which will include a second workshop, planned for the second half of 2014, to report on the progress of the research, framed by the key outcomes of the first workshop.

# 6 CONCLUSION

Over the last 15 years, the concept of industrial ecology has been applied in Australia at different levels—from SME-focused waste exchange networks to heavy industrial areas—with varying degree of success. Undoubtedly, it is now a well-recognised approach to increase resource efficiency and minimise environmental impacts associated with industrial and consumer activities. The country's unique geographic location as a continent, with long distances between major cities and industrial centres in regional areas, being the major challenge, also defines the opportunities to enhance the application of industrial ecology.

Most of the existing examples were implemented with the local and state government support (in different forms), while there are very few projects that have been developed and have succeeded solely on the basis of industry interest and funding. With a focus on technical feasibility and establishing inter-industry collaboration in the existing cases, there are still other barriers preventing waste and by-product exchanges from happening. The economic driver usually predetermines the investigation for waste reuse options, with environmental regulation being another important factor to stimulate or prevent any interest in establishing synergy connections and recycling.

This report has presented initial findings from applying the concept of industrial ecology for enhancing metals recycling in the Australian context focussing on investigating metal flows in the economy, estimating the potential of wealth from metal waste, as well as highlighting institutional and other non-technical barriers and enablers for existing and emerging recycling systems in Australia. The analysis presented in this report has taken a high-level approach to estimating and understanding the current state and future potential for recycling of metals in Australia. Future research work as part of this Cluster will provide more resolution in terms of the flows of key individual metals in the Australian economy.

Export of non-processed mineral resources provides significant revenue and has allowed the Australian economy to stably grow over the last few decades. However, primary extraction of mineral resources results in significant environmental impacts, and leads to the exhaustion of country's geological reserves, while recycling usually prevents environmental damage from landfilling of waste materials, saves energy on resources recovery versus primary production, and provides an alternative and potential stable (and growing) resource base for future collection and processing or re-processing.

Achieving a balance between the extraction and processing of raw materials, predominantly for export, requires Australian leadership in stewardship of material resources. Based on existing waste and recycling statistics in Australia, the estimated potential (lost opportunity) for "wealth from metal waste" is significant and of the order of AUD2 billion a year. A more innovative approach is required to financially benefit the economy from domestic recycling. This will allow for an expansion of the Australian resource base and could be the catalyst for new niche manufacturing and services companies based on recycling and re-use, which can then be exported to rest of the world.

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# 8 APPENDIX A. DATA AND STATISTICS

## A.1 AUSTRALIAN NATIONAL STATISTICS. BUREAU OF RESOURCES AND ENERGY ECONOMICS (BREE)

### A.1.1 AUSTRALIAN PRODUCTION OF MINERAL COMMODITIES. SOURCE: (BREE, 2013).

| | Unit | 2006–07 | 2007–08 | 2008–09 | 2009–10 | 2010–11 | 2011–12 | 2012–13 |
|---|---|---|---|---|---|---|---|---|
| Bauxite | Mt | 63 | 63 | 64 | 68 | 69 | 73 | 79 |
| Coal | | | | | | | | |
| Black | | | | | | | | |
| Salable | Mt | 325 | 326 | 340 | 367 | 345 | 364 | 401 |
| Raw | Mt | 417 | 423 | 446 | 475 | 454 | 480 | 527 |
| Brown | Mt | 66 | 66 | 68 | 69 | 66 | na | na |
| Copper in mine products s | kt | 859 | 847 | 890 | 819 | 952 | 926 | 963 |
| Diamonds | ’000 ct | 24 632 | 16 528 | 15 169 | 11 138 | 8 027 | 8 373 | 9 730 |
| Gold in mine products s | t | 251 | 230 | 218 | 240 | 265 | 255 | 254 |
| Iron ore and concentrate | Mt | 288 | 325 | 353 | 423 | 447 | 504 | 554 |
| Lead in mine products s | kt | 642 | 641 | 596 | 617 | 697 | 634 | 639 |
| Manganese ore and concentrate s | kt | 5 046 | 5 428 | 3 730 | 5 795 | 6 784 | 7 104 | 7 390 |
| Nickel in mine products s | kt | 191 | 190 | 185 | 157 | 195 | 235 | 242 |
| Petroleum | | | | | | | | |
| Crude oil and condensate s | ML | 27 651 | 25 610 | 26 407 | 25 583 | 25 772 | 24 068 | 21 268 |
| LPG (naturally occurring) | ML | 4 550 | 3 971 | 3 929 | 4 097 | 3 906 | 3 813 | 3 529 |
| Methane | $Mm^3$ | 37 007 s | 37 236 s | 38 266 s | 44 712 s | 46 851 s | 47 728 s | 54 390 s |
| Ethane | $Mm^3$ | 439 s | 454 s | 395 s | 311 s | 295 s | 344 s | 356 s |
| Coal seam gas | $Mm^3$ | 2 556 s | 3 473 s | 3 995 s | 5 100 s | 5 957 s | 7 631 s | 7 203 s |
| Salt s | kt | 11 229 | 9 826 | 11 314 | 11 772 | 11 562 | 11 413 s | 11 159 s |
| Silver in mine products s | t | 1 674 | 1 867 | 1 764 | 1 809 | 1 792 | 1 862 | 1 696 |
| Tin in mine products s | t | 2 061 | 1 767 | 4 045 | 19 829 | 18 410 | 8 150 | 6 637 |
| Titanium minerals | | | | | | | | |
| Ilmenite | kt | 2 383 | 2 205 | 1 932 | 1 398 | 1 275 | 1 331 | 1 335 |
| Rutile | kt | 279 | 332 | 285 | 361 | 467 | 440 | 465 |
| Synthetic rutile s | kt | 729 | 672 | 732 | 553 | 542 | 480 | 484 |
| Titanium dioxide pigment s | kt | 207 | 201 | 214 | 222 | 204 | 204 | 204 |
| Uranium | t | 9 589 | 10 123 | 10 311 | 7 109 | 7 069 | 7 657 | 8 919 |
| Zinc in mine products s | kt | 1 229 | 1 431 | 1 288 | 1 362 | 1 479 | 1 567 | 1 527 |
| Zircon concentrate | kt | 564 | 563 | 485 | 408 | 674 | 706 | 613 |

s BREE estimate.

*Sources:* BREE; ABARES; ABS; Energy Quest; state mines departments and their equivalents.

## A.1.2 AUSTRALIAN SMELTER AND REFINERY PRODUCTION OF MINERAL COMMODITIES. SOURCE: (BREE, 2013).

| | Unit | 2005–06 | 2006–07 | 2007–08 | 2008–09 | 2009–10 | 2010–11 | 2011–12 | 2012–13 |
|---|---|---|---|---|---|---|---|---|---|
| Alumina | kt | 17 826 | 18 506 | 19 359 | 19 597 | 20 057 | 19 041 | 19 283 | 21 645 |
| Aluminium | kt | 1 912 | 1 954 | 1 964 | 1 974 | 1 920 | 1 938 | 1 938 | 1 788 |
| Blister copper a | kt | 404 | 389 | 395 | 459 | 381 | 459 | 449 | 417 |
| Copper | kt | 461 | 435 | 444 | 499 | 395 | 485 | 486 | 454 |
| Gold e | | | | | | | | | |
| Australian origin | t | 209 | 208 | 190 | 179 | 194 | 210 | 204 | 204 |
| Overseas origin | t | 66 | 55 | 58 | 74 | 69 | 71 | 62 | 62 |
| Lead bullion a | kt | 141 | 114 | 152 | 155 | 148 | 133 | 144 | 148 |
| Lead b | kt | 234 | 191 | 203 | 213 | 189 | 190 | 174 | 159 |
| Nickel matte | kt | 47 | 57 | 45 | 21 | 43 | 60 | 70 | 61 |
| Nickel c | kt | 115 | 118 | 121 | 111 | 120 | 101 | 122 | 135 |
| Petroleum | | | | | | | | | |
| Automotive diesel oil | ML | 10 154 | 11 055 | 12 177 | 12 231 | 11 761 | 12 932 | 8 798 | 12 735 |
| Automotive gasoline | ML | 16 528 | 17 732 | 17 079 | 17 159 | 16 828 | 16 749 | 15 661 | 14 924 |
| Aviation turbine fuel | ML | 5 216 | 5 332 | 5 182 | 5 494 | 5 359 | 5 489 | 5 488 | 5 563 |
| Fuel oil | ML | 1 048 | 942 | 979 | 872 | 849 | 958 | 966 | 905 |
| Raw steel d | kt | 7 866 | 8 010 | 8 151 | 5 568 | 6 886 | 7 305 | 5 383 | 4 850 |
| Silver | t | 655 | 618 | 605 | 751 | 698 | 712 | 847 | 1 057 |
| Tin | t | 736 | 321 | na | na | na | na | na | na |
| Zinc | kt | 446 | 496 | 507 | 506 | 515 | 499 | 505 | 496 |

a Metallic content. b Includes lead content of lead alloys from primary sources. c Includes nickel contained in metal and nickel oxide. d Includes recovery from scrap. e Includes refined gold from primary sources only. na Not available.

*Sources:* BREE, ABARES; DRET.

## A.1.3 VOLUME OF AUSTRALIAN EXPORTS OF MINERAL COMMODITIES. SOURCE: (BREE, 2013).

| | Unit | 2006–07 | 2007–08 | 2008–09 | 2009–10 | 2010–11 | 2011–12 | 2012–13 |
|---|---|---|---|---|---|---|---|---|
| Bauxite | kt | 5 700 | 7 917 | 7 470 | 8 023 | 8 595 | 10 518 | 12 567 |
| Alumina | kt | 15 056 | 15 739 | 16 395 | 16 653 | 16 227 | 16 592 | 18 914 |
| Aluminium (ingot metal) | kt | 1 638 | 1 650 | 1 748 | 1 624 | 1 686 | 1 693 | 1 569 |
| Coal, black | | | | | | | | |
| Metallurgical | Mt | 132 | 137 | 125 | 157 | 140 | 142 | 154 |
| Thermal | Mt | 112 | 115 | 136 | 135 | 143 | 158 | 182 |
| Copper s | kt | 699 | 732 | 815 | 805 | 877 | 926 | 977 |
| Diamonds s | '000 ct | 24 632 | 16 528 | 16 279 | 10 355 | 9 900 | 11 526 | 12 160 |
| Gold, refined | t | 400 | 382 | 437 | 335 | 301 | 304 | 280 |
| Iron and steel | | | | | | | | |
| Iron ore and pellets | Mt | 257 | 294 | 324 | 390 | 407 | 470 | 527 |
| Iron and steel | kt | 2 648 | 2 131 | 1 741 | 1 549 | 1 785 | 1 186 | 993 |
| Ferroalloys | kt | 5 | 1 | 3 | 4 | 3 | 8 | 1 |
| Lead s | kt | 635 | 588 | 645 | 658 | 676 | 703 | 678 |
| Magnesia | t | 139 787 | 161 531 | 108 806 | 131 264 | 199 069 | 172 992 | 28 731 |
| Manganese ore and concentrate s | kt | 4 667 | 5 105 | 3 226 | 5 648 | 6 190 | 6 853 | 6 718 |
| Petroleum | | | | | | | | |
| Crude oil and other refinery feedstock | ML | 15 965 | 15 975 | 16 588 | 18 064 | 19 638 | 19 212 | 18 757 |
| LNG s | Mt | 14 | 14 | 15 | 18 | 20 | 19 | 24 |
| LPG | ML | 2 824 | 2 589 | 2 500 | 2 776 | 2 471 | 2 115 | 2 386 |
| Refinery products | ML | 1 752 | 1 807 | 1 164 | 850 | 760 | 1 151 | 943 |
| Salt | kt | 10 749 | 10 686 | 10 978 | 11 185 | 11 162 | 10 884 | 10 773 |
| Silver, refined bullion | t | 431 | 335 | 423 | 420 | 198 | 269 | 497 |
| Tin s | t | 1 867 | 3 079 | 4 159 | 6 031 | 5 426 | 4 895 | 6 322 |
| Titanium minerals | | | | | | | | |
| Ilmenite concentrate a | kt | 999 | 894 | 1 538 | 1 763 | 1 804 | 2 045 | 2 040 |
| Leucoxene | kt | 134 | 69 | 61 | 18 | 27 | 31 | 31 |
| Rutile concentrate | kt | 307 | 399 | 550 | 575 | 491 | 334 | 368 |
| Synthetic rutile s | kt | 508 | 513 | 512 | 513 | 517 | 536 | 485 |
| Titanium dioxide pigment | kt | 171 | 175 | 141 | 181 | 195 | 179 | 142 |
| Uranium oxide ($U_3O_8$) | t | 9 519 | 10 139 | 10 114 | 7 555 | 6 950 | 6 917 | 8 675 |
| Zinc s | kt | 1 321 | 1 507 | 1 471 | 1 482 | 1 494 | 1 572 | 1 596 |
| Zircon concentrate b | kt | 555 | 637 | 685 | 748 | 963 | 846 | 779 |

a Bulk only. b All grades. s BREE estimate.
*Sources:* BREE; ABARES, *Australian Mineral Statistics,* Canberra; ABS, *International Trade, Australia*, cat. no. 5465.0, Canberra.

## A.1.4 VALUE OF AUSTRALIAN EXPORTS OF MINERAL COMMODITIES. SOURCE: (BREE, 2013).

| | 2006–07 $m | 2007–08 $m | 2008–09 $m | 2009–10 $m | 2010–11 $m | 2011–12 $m | 2012–13 $m |
|---|---|---|---|---|---|---|---|
| Bauxite s | 108 | 206 | 192 | 178 | 229 | 296 | 382 |
| Alumina a | 6 243 | 5 809 | 6 015 | 4 969 | 5 218 | 5 146 | 5 342 |
| Aluminium (ingot metal) | 5 650 | 4 967 | 4 724 | 3 838 | 4 178 | 3 797 | 3 276 |
| Coal, black | | | | | | | |
| Metallurgical | 15 039 | 16 038 | 36 813 | 24 526 | 29 793 | 30 700 | 22 441 |
| Thermal | 6 758 | 8 365 | 17 885 | 11 886 | 13 956 | 17 118 | 16 162 |
| Copper b | 6 526 | 6 730 | 5 863 | 6 506 | 8 422 | 8 501 | 8 067 |
| Diamonds cs | 726 | 625 | 676 | 471 | 366 | 386 | 398 |
| Gems, other than diamonds | 49 | 52 | 43 | 40 | 49 | 47 | 55 |
| Gold, refined | 10 320 | 10 903 | 16 146 | 12 996 | 13 016 | 15 462 | 15 056 |
| Iron and steel | | | | | | | |
| Iron ore and pellets | 15 512 | 20 511 | 34 239 | 35 075 | 58 387 | 62 695 | 57 082 |
| Iron and steel | 1 743 | 1 562 | 1 363 | 1 120 | 1 303 | 983 | 820 |
| Lead b | 1 579 | 2 027 | 1 637 | 1 833 | 2 059 | 2 200 | 1 943 |
| Magnesia | 66 | 72 | 82 | 61 | 108 | 105 | 13 |
| Manganese ore and concentrate s | 482 | 1 532 | 1 406 | 1 395 | 1 407 | 1 229 | 1 347 |
| Nickel s | 7 912 | 5 412 | 2 717 | 3 875 | 4 096 | 4 056 | 3 644 |
| Petroleum | | | | | | | |
| Crude oil and other refinery feedstock | 8 317 | 10 484 | 8 757 | 9 534 | 12 245 | 13 205 | 12 506 |
| LNG | 5 222 | 5 854 | 10 079 | 7 789 | 10 437 | 11 949 | 13 741 |
| LPG | 1 038 | 1 182 | 1 044 | 1 105 | 1 068 | 971 | 1 090 |
| Refinery products | 1 098 | 1 323 | 788 | 566 | 526 | 890 | 692 |
| Salt | 239 | 232 | 237 | 247 | 251 | 245 | 242 |
| Silver d | 221 | 187 | 245 | 254 | 164 | 268 | 535 |
| Tin b | 25 | 42 | 70 | 101 | 126 | 102 | 123 |
| Titanium minerals | | | | | | | |
| Ilmenite concentrate e | 113 | 104 | 171 | 197 | 198 | 225 | 224 |
| Leucoxene concentrate | 42 | 23 | 37 | 11 | 17 | 22 | 22 |
| Rutile concentrate | 259 | 277 | 335 | 382 | 390 | 252 | 261 |
| Synthetic rutile s | 361 | 305 | 258 | 269 | 315 | 294 | 264 |
| Titanium doxide pigment | 408 | 375 | 396 | 448 | 527 | 571 | 385 |
| Uranium oxide ($U_3O_8$) | 660 | 887 | 990 | 757 | 610 | 607 | 739 |
| Zinc b | 4 298 | 3 350 | 1 858 | 2 214 | 2 373 | 2 292 | 2 194 |
| Zircon concentrate f | 478 | 421 | 540 | 370 | 532 | 327 | 194 |
| Other mineral resources | 4 789 | 6 110 | 4 721 | 5 222 | 5 466 | 6 088 | 6 651 |
| Total mineral resources g | 106 220 | 115 904 | 160 251 | 138 183 | 177 729 | 190 934 | 175 888 |

a Includes aluminium hydroxide. b Value of all ores, concentrates, intermediate products (where applicable) and refined metal. c Unsorted and sorted. d Includes refined bullion, powder, unwrought silver and semimanufactured forms. e Bulk ilmenite. f All grades. g Total mineral resources exports on a BREE balance of payments basis. s BREE estimate.

*Sources:* BREE; ABARES, *Australian Mineral Statistics,* Canberra; ABS, *International Trade, Australia,* cat. no. 5465.0, Canberra.

## A.1.5 VALUE OF AUSTRALIAN EXPORTS OF MINERALS, BY DESTINATION. SOURCE: (BREE, 2013).

| | 1997–98 $m | 1998–99 $m | 1999–00 $m | 2000–01 $m | 2001–02 $m | 2002–03 $m | 2003–04 $m | 2004–05 $m |
|---|---|---|---|---|---|---|---|---|
| Africa | 231 | 180 | 153 | 263 | 364 | 415 | 440 | 409 |
| Americas | | | | | | | | |
| United States | 1 931 | 1 227 | 1 798 | 2 109 | 1 585 | 1 435 | 1 141 | 1 167 |
| Other | 544 | 582 | 564 | 676 | 827 | 900 | 592 | 660 |
| Asia | | | | | | | | |
| China | 1 498 | 1 626 | 2 036 | 2 769 | 2 990 | 3 569 | 4 550 | 6 789 |
| Chinese Taipei | 2 566 | 2 599 | 2 956 | 4 039 | 3 159 | 2 653 | 2 162 | 3 165 |
| Hong Kong, China | 1 693 | 1 108 | 1 011 | 1 266 | 1 374 | 991 | 746 | 768 |
| India | 921 | 1 195 | 949 | 1 305 | 1 732 | 1 981 | 4 091 | 5 156 |
| Japan | 10 545 | 10 008 | 11 337 | 15 034 | 14 855 | 14 355 | 12 533 | 16 963 |
| Korea, Rep. of | 4 520 | 4 420 | 4 647 | 5 958 | 6 162 | 5 743 | 5 175 | 6 211 |
| Singapore | 1 920 | 1 694 | 3 260 | 4 061 | 2 803 | 2 791 | 1 540 | 1 629 |
| Other | 2 106 | 1 821 | 2 287 | 2 786 | 2 807 | 2 637 | 3 082 | 5 064 |
| Europe | | | | | | | | |
| France | 294 | 380 | 309 | 443 | 521 | 427 | 348 | 479 |
| Germany | 478 | 416 | 383 | 421 | 381 | 325 | 297 | 334 |
| Netherlands | 279 | 347 | 463 | 795 | 766 | 644 | 626 | 913 |
| United Kingdom | 1 097 | 2 456 | 1 537 | 1 469 | 2 009 | 2 852 | 1 857 | 1 780 |
| Other European Union | 1 173 | 1 306 | 1 172 | 1 452 | 1 743 | 1 402 | 1 365 | 1 714 |
| Other Europe | 1 000 | 332 | 185 | 155 | 91 | 186 | 124 | 179 |
| Oceania | | | | | | | | |
| New Zealand | 739 | 719 | 858 | 989 | 1 207 | 1 102 | 941 | 1 528 |
| Other | 511 | 407 | 550 | 860 | 525 | 516 | 369 | 469 |
| Other | 5 448 | 5 560 | 6 815 | 8 201 | 8 261 | 7 214 | 6 477 | 7 563 |
| **Total** | **39 465** | **38 360** | **43 253** | **55 040** | **54 151** | **52 125** | **48 456** | **62 941** |

| | 2005–06 $m | 2006–07 $m | 2007–08 $m | 2008–09 $m | 2009–10 $m | 2010–11 $m | 2011–12 $m | 2012–13 $m |
|---|---|---|---|---|---|---|---|---|
| Africa | 631 | 574 | 416 | 768 | 567 | na | na | na |
| Americas | | | | | | | | |
| United States | 1 198 | 1 239 | 2 007 | 2 215 | 1 665 | na | na | na |
| Other | 1 814 | 1 588 | 1 332 | 2 589 | 2 004 | na | na | na |
| Asia | | | | | | | | |
| China | 10 970 | 13 201 | 19 567 | 33 156 | 36 806 | 49 937 | 64 049 | 64 929 |
| Chinese Taipei | 4 100 | 4 716 | 4 906 | 5 952 | 5 066 | na | na | na |
| Hong Kong, China | 908 | 1 064 | 710 | 696 | 611 | na | na | na |
| India | 6 421 | 8 843 | 8 444 | 13 902 | 14 870 | 14 278 | 11 909 | 9 818 |
| Japan | 23 853 | 24 930 | 27 194 | 43 996 | 31 172 | na | na | na |
| Korea, Rep. of | 8 344 | 9 552 | 10 902 | 17 088 | 13 330 | na | na | na |
| Singapore | 2 391 | 2 932 | 3 040 | 3 062 | 2 772 | na | na | na |
| Other | 5 814 | 7 822 | 8 263 | 7 749 | 6 980 | na | na | na |
| Europe | | | | | | | | |
| France | 683 | 701 | 583 | 841 | 623 | na | na | na |
| Germany | 492 | 540 | 479 | 1 246 | 945 | na | na | na |
| Netherlands | 1 555 | 1 627 | 1 391 | 1 669 | 941 | na | na | na |
| United Kingdom | 3 543 | 2 822 | 5 254 | 8 669 | 5 115 | na | na | na |
| Other European Union | 3 033 | 4 053 | 3 861 | 3 425 | 2 065 | na | na | na |
| Other Europe | 106 | 1 034 | 863 | 400 | 130 | na | na | na |
| Oceania | | | | | | | | |
| New Zealand | 1 154 | 1 689 | 1 667 | 1 153 | 856 | na | na | na |
| Other | 740 | 610 | 612 | 511 | 615 | na | na | na |
| Other | 8 772 | 10 492 | 10 898 | 10 449 | 6 903 | na | na | na |
| **Total** | **86 523** | **100 026** | **112 388** | **159 537** | **134 998** | **na** | **na** | **na** |

a Not on a balance of payments basis; totals differ from earlier tables.
*Source:* BREE; ABARES; ABS, *International Trade, Australia*, cat. no. 5465.0, Canberra.

## A.1.6 VOLUME OF AUSTRALIAN IMPORTS OF MINERAL COMMODITIES. SOURCE: (BREE, 2013).

| | Unit | 2006–07 | 2007–08 | 2008–09 | 2009–10 | 2010–11 | 2011–12 | 2012–13 |
|---|---|---|---|---|---|---|---|---|
| Clays | kt | 63 | 70 | 55 | 64 | 61 | 57 | 72 |
| Diamonds a | ’000 ct | 3 430 | 2 964 | 767 | 1 024 | 1 189 | 638 | 407 |
| Iron and steel | | | | | | | | |
| Iron ore and pellets b | kt | 4 722 | 4 401 | 3 599 | 5 094 | 5 442 | 4 555 | 4 181 |
| Iron and steel | kt | 2 318 | 1 848 | 2 082 | 1 736 | 1 867 | 1 841 | 1 677 |
| Ferroalloys | kt | 87 | 97 | 54 | 71 | 69 | 65 | 56 |
| Limestone | kt | 567 | 693 | 451 | 682 | 523 | 571 | 562 |
| Magnesium | kt | 8 | 9 | 7 | 6 | 6 | 7 | 6 |
| Petroleum | | | | | | | | |
| Crude oil and other refinery feedstock | ML | 25 345 | 26 223 | 24 302 | 27 284 | 32 225 | 29 495 | 29 967 |
| Natural gas s | kt | 4 268 | 4 032 | 4 752 | 4 149 | 4 799 | 4 273 | 4 792 |
| Other refinery products s | ML | 14 018 | 17 982 | 19 697 | 19 967 | 18 762 | 22 194 | 23 659 |
| Phosphate rock | kt | 472 | 707 | 540 | 85 | 408 | 319 | 423 |
| Platinum and platinum group metals | kg | 4 571 | 2 518 | 1 203 | 2 461 | 3 562 | 2 833 | 2 099 |
| Potassium fertiliser | kt | 306 | 465 | 331 | 274 | 298 | 292 | 332 |
| Sulphur | kt | 37 | 202 | 75 | 1 | 44 | 256 | 452 |

a Includes sorted and unsorted, gem and industrial diamonds, and diamond dust and powder. b Includes limonite ore used for the production of refined nickel products. c Includes automotive diesel oil and industrial marine diesel fuel. s BREE estimate.

*Sources:* BREE; ABARES, *Australian Mineral Statistics,* Canberra; ABS, *International Trade, Australia*, cat. no. 5465.0, Canberra.

## A.1.7 VALUE OF AUSTRALIAN IMPORTS OF MINERAL COMMODITIES. SOURCE: (BREE, 2013).

| | 2006–07 $m | 2007–08 $m | 2008–09 $m | 2009–10 $m | 2010–11 $m | 2011–12 $m | 2012–13 $m |
|---|---|---|---|---|---|---|---|
| Clays | 16 | 18 | 18 | 14 | 15 | 15 | 18 |
| Diamonds a | 397 | 444 | 417 | 442 | 397 | 407 | 414 |
| Gold b | 5 309 | 7 311 | 11 250 | 7 739 | 5 426 | 6 814 | 4 885 |
| Iron and steel | | | | | | | |
| Iron ore and pellets c | 338 | 311 | 269 | 259 | 417 | 223 | 117 |
| Iron and steel | 2 479 | 2 225 | 3 191 | 1 889 | 2 121 | 2 113 | 1 755 |
| Ferroalloys | 116 | 154 | 181 | 118 | 127 | 106 | 85 |
| Limestone | 8 | 8 | 8 | 10 | 8 | 10 | 10 |
| Magnesium | 20 | 30 | 35 | 18 | 19 | 23 | 17 |
| Petroleum | | | | | | | |
| Crude oil and other refinery feedstock | 13 360 | 17 149 | 14 727 | 15 031 | 20 183 | 21 125 | 20 396 |
| Natural gas s | 800 | 724 | 2 166 | 1 219 | 1 929 | 2 151 | 2 421 |
| Other refinery products s | 7 784 | 12 730 | 13 129 | 11 296 | 11 445 | 16 720 | 17 948 |
| Phosphate rock | 32 | 80 | 193 | 10 | 57 | 55 | 64 |
| Platinum and platinum group metals | 186 | 111 | 29 | 92 | 151 | 104 | 44 |
| Potassium fertiliser | 85 | 165 | 355 | 143 | 129 | 146 | 160 |
| Silver | 98 | 80 | 223 | 107 | 490 | 950 | 435 |
| Sulphur | 34 | 101 | 152 | 29 | 90 | 138 | 158 |
| **Total** | **31 782** | **42 588** | **47 229** | **39 741** | **44 277** | **52 724** | **50 539** |

a Includes sorted and unsorted, gem and industrial diamonds, and diamond dust and powder. b Refined and unrefined bullion. c Includes value of limonite ore used for the production of refined nickel products. d Includes automotive diesel oil and industrial and marine diesel fuel. s BREE estimate.

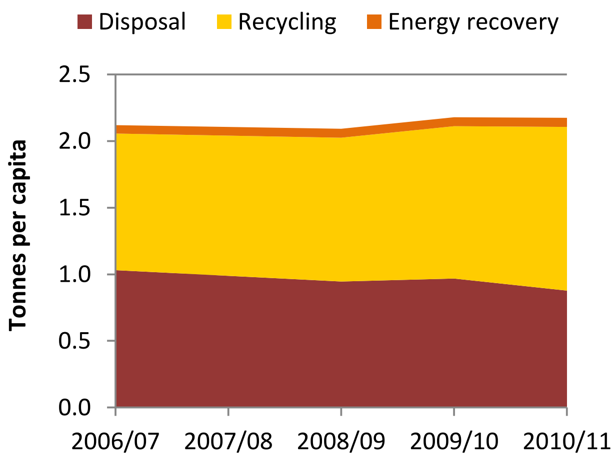
*Sources:* BREE; ABARES, *Australian Mineral Statistics,* Canberra; ABS, *International Trade, Australia*, cat. no. 5465.0, Canberra.

## A.1.8 WORLD PRODUCTION OF SELECTED METALS, 1968-2012. SOURCE: (BREE, 2013).

| Year | Iron and steel | | Aluminium | | | Copper | | | Zinc | | | Lead | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Crude | Refined metal | | | Refined metal | | | Refined metal | | | Refined metal | | |
| | Iron | steel | Primary | Secondary | Total | Smelter | Secondary | Total | Primary | Secondary | Total | Primary | Secondary | Total |
| | Mt | Mt | kt | kt | kt | kt | kt | kt | kt | kt | kt | kt | kt | kt |
| 1968 | 378.4 | 523.9 | 5 592 | 1 946 | 7 538 | 5 510 | 3 176 | 6 653 | 4 613 | 224 | 4 837 | 3 094 | 1 044 | 4 138 |
| 1969 | 408.4 | 570.9 | 6 160 | 2 256 | 8 416 | 5 965 | 3 452 | 7 205 | 5 073 | 205 | 5 278 | 3 894 | 1 148 | 4 542 |
| 1970 | 426.5 | 595.3 | 6 583 | 2 181 | 8 764 | 6 308 | 3 298 | 7 583 | 4 975 | 259 | 5 234 | 3 616 | 1 287 | 4 688 |
| 1971 | 423.1 | 582.3 | 7 439 | 2 295 | 9 734 | 6 374 | 3 155 | 7 393 | 4 862 | 248 | 5 110 | 3 388 | 1 261 | 4 614 |
| 1972 | 447.1 | 630.2 | 8 056 | 2 451 | 10 507 | 7 007 | 3 272 | 8 084 | 5 247 | 269 | 5 516 | 3 491 | 1 324 | 4 803 |
| 1973 | 493.5 | 696.4 | 8 621 | 2 817 | 11 438 | 7 286 | 3 639 | 8 525 | 5 543 | 283 | 5 826 | 3 580 | 1 426 | 4 991 |
| 1974 | 503.4 | 703.5 | 9 205 | 2 887 | 12 092 | 7 565 | 3 502 | 8 759 | 5 720 | 274 | 5 994 | 3 593 | 1 462 | 5 042 |
| 1975 | 469.9 | 643.5 | 10 129 | 2 542 | 12 671 | 7 280 | 2 699 | 8 177 | 5 219 | 264 | 5 483 | 3 442 | 1 410 | 4 828 |
| 1976 | 489.4 | 675.1 | 12 863 | 2 781 | 15 644 | 7 616 | 3 163 | 8 624 | 5 545 | 266 | 5 811 | 3 539 | 1 487 | 5 049 |
| 1977 | 485.8 | 675.3 | 14 322 | 3 052 | 17 374 | 7 810 | 3 109 | 8 878 | 5 710 | 279 | 5 989 | 3 662 | 1 707 | 5 372 |
| 1978 | 506.7 | 716.5 | 14 776 | 3 240 | 18 016 | 7 686 | 3 313 | 9 020 | 5 801 | 237 | 6 038 | 3 697 | 1 738 | 5 459 |
| 1979 | 528.3 | 746.7 | 15 175 | 3 316 | 18 491 | 7 738 | 3 668 | 9 181 | 6 169 | 287 | 6 456 | 3 716 | 1 903 | 5 622 |
| 1980 | 508.1 | 716.3 | 16 035 | 3 318 | 19 353 | 7 681 | 3 738 | 9 297 | 5 958 | 285 | 6 243 | 3 600 | 1 815 | 5 417 |
| 1981 | 497.2 | 707.1 | 15 698 | 3 618 | 19 316 | 8 036 | 3 671 | 9 545 | 5 969 | 318 | 6 287 | 3 560 | 1 798 | 5 309 |
| 1982 | 452.6 | 644.9 | 13 990 | 3 583 | 17 573 | 7 850 | 3 518 | 9 378 | 5 701 | 355 | 6 056 | 3 641 | 1 649 | 5 210 |
| 1983 | 458.1 | 663.4 | 14 334 | 3 960 | 18 294 | 8 379 | 3 688 | 9 694 | 6 016 | 368 | 6 384 | 3 637 | 1 561 | 5 198 |
| 1984 | 490.7 | 710.3 | 15 941 | 3 950 | 19 891 | 8 684 | 3 848 | 9 512 | 6 327 | 351 | 6 678 | 3 470 | 1 829 | 5 299 |
| 1985 | 499.6 | 718.9 | 15 555 | 4 022 | 19 577 | 8 933 | 3 837 | 9 689 | 6 545 | 325 | 6 870 | 3 539 | 1 835 | 5 374 |
| 1986 | 496.3 | 714.0 | 15 619 | 4 196 | 19 815 | 9 165 | 3 905 | 9 862 | 6 085 | 295 | 6 380 | 3 345 | 1 891 | 5 236 |
| 1987 | 509.0 | 735.5 | 16 483 | 4 511 | 20 994 | 9 287 | 3 996 | 10 160 | 6 330 | 293 | 6 623 | 3 386 | 2 047 | 5 433 |
| 1988 | 538.4 | 780.1 | 18 575 | 4 943 | 23 518 | 9 372 | 4 307 | 10 485 | 6 579 | 299 | 6 878 | 3 475 | 2 102 | 5 577 |
| 1989 | 544.8 | 785.9 | 19 135 | 4 943 | 24 078 | 9 720 | 4 250 | 10 858 | 6 426 | 368 | 6 794 | 3 362 | 2 348 | 5 710 |
| 1990 | 531.6 | 770.1 | 19 348 | 5 062 | 24 410 | 9 132 | 4 325 | 10 809 | 6 296 | 395 | 7 061 | 3 087 | 2 369 | 5 456 |
| 1991 | 508.6 | 736.2 | 19 653 | 5 336 | 24 988 | 9 066 | 4 317 | 10 688 | 6 427 | 428 | 7 249 | 3 071 | 2 262 | 5 325 |
| 1992 | 476.4 | 719.6 | 19 459 | 5 476 | 24 935 | 9 730 | 4 408 | 11 170 | 6 605 | 425 | 7 028 | 3 238 | 2 268 | 5 437 |
| 1993 | 477.4 | 727.6 | 19 715 | 6 058 | 25 773 | 9 671 | 4 948 | 11 306 | 6 755 | 455 | 7 195 | 3 176 | 2 303 | 5 479 |
| 1994 | 482.6 | 725.1 | 19 112 | 6 447 | 25 559 | 9 740 | 5 026 | 11 166 | 6 700 | 467 | 7 130 | 2 968 | 2 483 | 5 462 |
| 1995 | 524.2 | 752.3 | 19 668 | 6 876 | 26 544 | 9 745 | 5 337 | 11 817 | 6 850 | 497 | 7 330 | 3 091 | 2 649 | 5 740 |
| 1996 | 517.4 | 750.1 | 20 848 | 6 914 | 27 762 | 10 407 | 5 917 | 12 756 | 6 919 | 524 | 7 443 | 3 074 | 2 784 | 5 822 |
| 1997 | 546.6 | 798.9 | 21 798 | 7 484 | 29 282 | 10 779 | 6 200 | 13 600 | 7 283 | 500 | 7 782 | 3 127 | 2 905 | 6 033 |
| 1998 | 539.5 | 777.3 | 22 654 | 7 594 | 30 248 | 10 928 | 5 976 | 14 120 | 7 503 | 518 | 8 021 | 3 095 | 2 918 | 6 010 |
| 1999 | 541.1 | 789.0 | 23 707 | 8 132 | 31 839 | 11 494 | 5 883 | 14 465 | 7 816 | 552 | 8 374 | 3 291 | 2 990 | 6 280 |
| 2000 | 576.3 | 847.7 | 24 418 | 8 389 | 32 807 | 11 888 | 6 028 | 14 816 | 8 382 | 599 | 8 981 | 3 546 | 3 109 | 6 655 |
| 2001 | 578.4 | 850.4 | 24 436 | 7 864 | 32 300 | 12 379 | 5 747 | 15 675 | 8 599 | 622 | 9 268 | 3 521 | 3 072 | 6 594 |
| 2002 | 611.0 | 903.9 | 26 076 | 7 910 | 33 986 | 11 958 | 5 427 | 15 336 | 9 082 | 628 | 9 710 | 3 560 | 3 110 | 6 670 |
| 2003 | 670.1 | 969.7 | 28 002 | 8 113 | 36 116 | 12 055 | 5 367 | 15 220 | 9 281 | 593 | 9 874 | 3 647 | 3 117 | 6 762 |
| 2004 | 724.1 | 1 068.6 | 29 940 | 8 395 | 38 335 | 12 347 | 5 484 | 15 840 | 9 801 | 552 | 10 353 | 3 776 | 3 181 | 6 954 |
| 2005 | 793.5 | 1 146.2 | 31 889 | 8 599 | 40 488 | 13 000 | 5 558 | 16 648 | 9 699 | 523 | 10 221 | 4 375 | 3 248 | 7 623 |
| 2006 | 875.0 | 1 250.2 | 33 975 | 9 092 | 43 067 | 13 406 | 5 909 | 17 353 | 9 876 | 753 | 10 629 | 3 767 | 4 340 | 8 103 |
| 2007 | 946.3 | 1 343.5 | 38 186 | 9 662 | 47 848 | 13 516 | 5 996 | 18 043 | 10 553 | 792 | 11 345 | 3 573 | 4 852 | 8 351 |

| Year | Iron and steel | | Aluminium | | | Copper | | | Zinc | | | Lead | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Refined metal | | | Refined metal | | | Refined metal | | | Refined metal | | |
| | Iron | Crude steel | Primary | Secondary | Total | Smelter | Secondary | Total | Primary | Secondary | Total | Primary | Secondary | Total |
| | Mt | Mt | kt | kt | kt | kt | kt | kt | kt | kt | kt | kt | kt | kt |
| 2008 | 927.4 | 1 329.7 | 39 960 | 8 839 | 48 799 | 13 855 | 5 993 | 18 501 | 10 987 | 787 | 11 774 | 4 014 | 5 190 | 9 075 |
| 2009 | 900.2 | 1 219.7 | 37 162 | 7 927 | 45 089 | 14 074 | 5 749 | 18 567 | 10 631 | 650 | 11 281 | 3 786 | 5 411 | 9 197 |
| 2010 | 1 037.0 | 1 415.3 | 41 504 | 8 267 | 49 771 | 14 414 | 6 180 | 19 233 | 12 099 | 796 | 12 895 | 4 047 | 5 758 | 9 805 |
| 2011 | 1 086 | 1 510 | 44 776 | 8 858 | 53 634 | 14 312 | 6 412 | 19 839 | 12 246 | 834 | 13 073 | 4 522 | 6 023 | 10 545 |
| 2012 | 1 107 | 1 534 | 46 306 | 9 106 | 55 411 | 14 411 | 6 530 | 20 315 | 11 792 | 801 | 12 589 | 4 632 | 5 893 | 10 525 |

## A.2 AUSTRALIA, WASTE MANAGEMENT TIME SERIES. DEPARTMENT OF SUSTAINABILITY, ENVIRONMENT, WATER, POPULATION AND COMMUNITIES (DSEWPC)



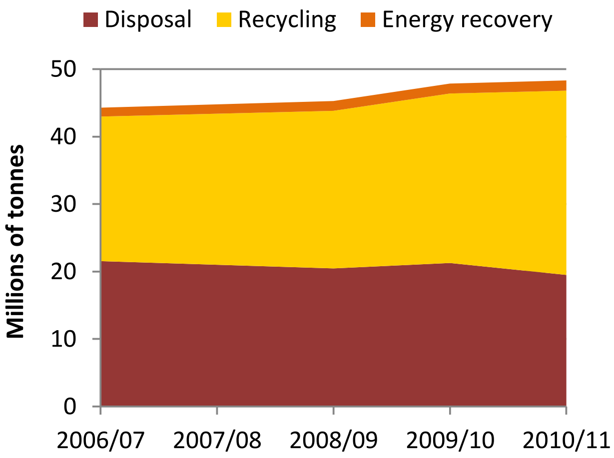




**Figure A1:** Trends in per capita and total waste generation and management, 2006/07 to 2010/11 (excl. fly ash). *Source: (Randell et al., 2014).*

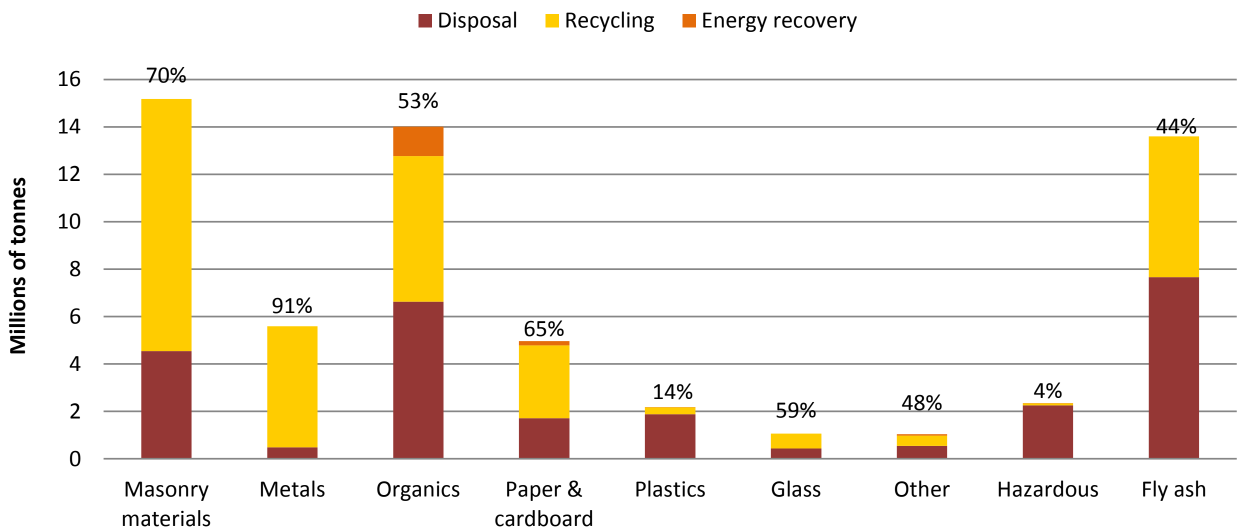



**Figure A2:** Australia 2010/11, total waste generation by material category and management. *Source: (Randell et al., 2014).*

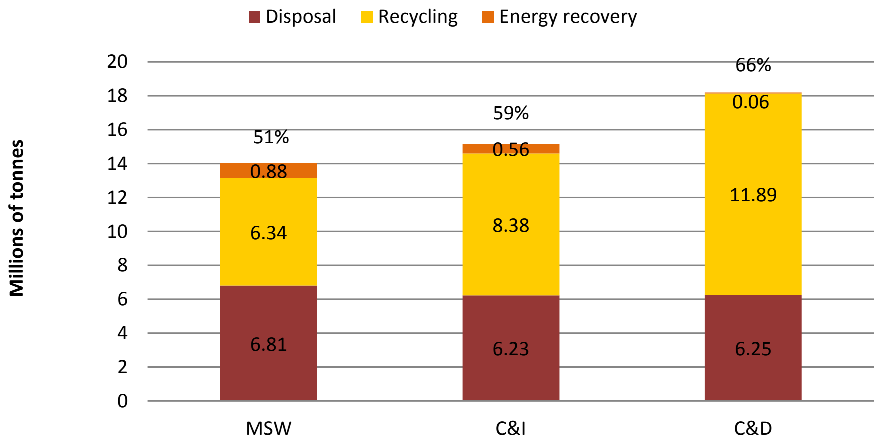



**Figure A3:** Australia 2010/11, total waste generation by waste stream and management (excluding ACT). *Source: (Randell et al., 2014).*

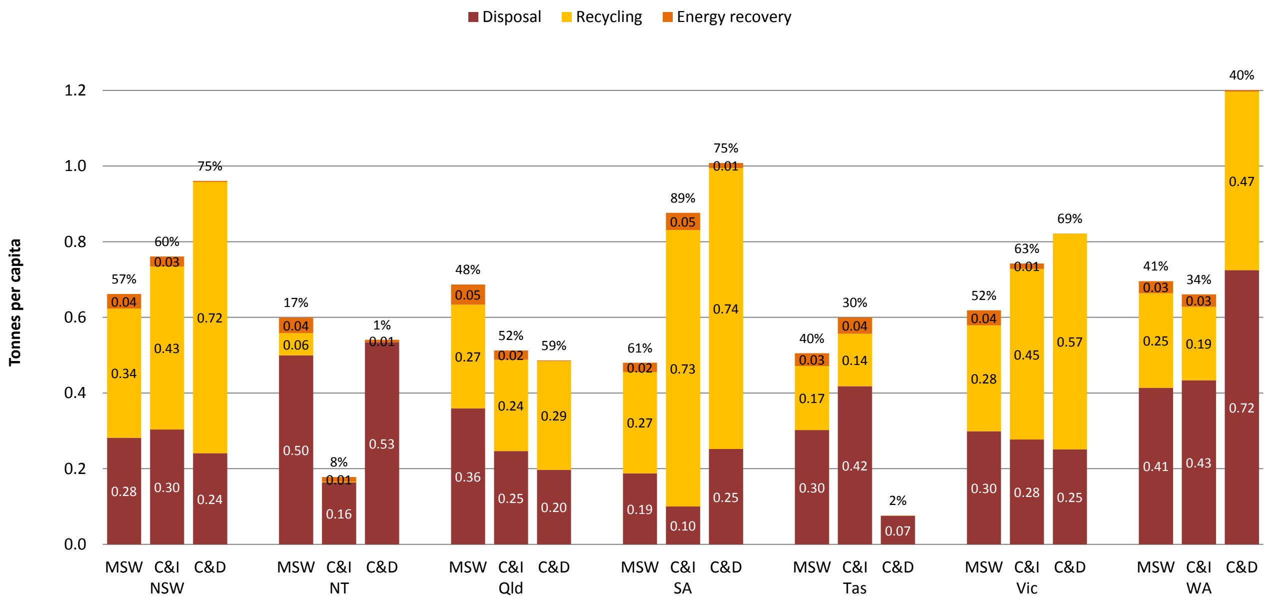



**Figure A4:** Australia 2010/11, per capita waste generation by waste stream, management, and jurisdiction (excluding ACT). *Source: (Randell et al., 2014).*

**FOR FURTHER INFORMATION**

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