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Resource circular economy: Opportunities to reduce waste disposal across the supply chain

Steel

Research Report 5

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EXECUTIVE SUMMARY

Steel is one of the most common materials used in construction for several centuries. There are a number of different kinds of steel used for construction. Indeed, construction is one of the most important steel-using industries, accounting for more than 50% of world steel demand. Structural steel fabricating industry has derived solid demand from the key building markets over the past five years, although declining demand from the non-building and mining infrastructure markets has negatively affected the industry's performance. The constant threat of competition from low-priced imports has also limited industry revenue growth over the period. According to the available data in the study period, 3,822,990 tonnes of steel waste was generated in Australia. Among the state and territories, the largest volume was generated in NSW (1,345,349 t), Vic (925,563 t) and Qld (703,502 t). Except for SA with 3,155 tonnes of landfilled steel waste, other states did not report their disposal rate.

The following are the recommendations for maximising the opportunities for reducing steel waste in various stages of construction and demolition activities.

- Provision of landfill levy exemption for MRT’s steel recycling
- Adjust specifications in favour of more usage of steel waste-based materials in new constructions project
- Stabilise market volatility to ensure sustainable usage of steel waste in steel manufacturing
- The government needs to offer freight subsidises to enable the delivery of recyclables to processing facilities

1 INTRODUCTION

Steel is one of the most common materials used in construction for several centuries. Early processes of steel making were made during the classical era in Ancient Iran, Ancient China, India, and Rome. Praised for its versatility, extremely high tensile strength and value, it is widely used in everything from residential construction to buildings skyscrapers. There are a number of different kinds of steel used for construction. Indeed, construction is one of the most important steel-using industries, accounting for more than 50% of world steel demand. Steel is an alloy of iron and carbon, and sometimes other elements. Table 1 shows the main properties of steel that explains its wide application in the construction industry.

Table 1. Main properties of steel in the construction industry

Property	Description
Strength, beauty, design freedom	Steel offers architects more design freedom in colour, texture and shape. Its combination of strength, durability, beauty, precision and malleability gives architects broader parameters to explore ideas and develop fresh solutions. Steel's long spanning ability gives rise to large open spaces, free of intermediate columns or load bearing walls. Its capacity to bend to a certain radius, creating segmented curves or free-form combinations for facades, arches or domes sets it apart. Factory-finished to the most exacting specifications under highly controlled conditions, steel's final outcome is more predictable and repeatable, eliminating the risk of on-site variability.
Fast, efficient, resourceful	Steel can be assembled quickly and efficiently in all seasons. Components are pre-manufactured off site with minimal on-site labour. A whole frame can be erected in a matter of days rather than weeks, with a corresponding 20% to 40% reduction in construction time relative to on-site construction, depending on a project's scale. For single dwellings, on more challenging sites, steel often allows less points of contact with the earth, reducing the amount of excavation required. Structural steel's lighter weight relative to other framing materials such as concrete enables a smaller, simpler foundation. These efficiencies in execution translate to considerable resource efficiencies and economic benefits, including accelerated project schedules, reduced site management costs and an earlier return on investment.
Adaptable and accessible	These days, a building's function can change dramatically and rapidly. A tenant may want to make changes that increase floor loads significantly. Walls may need to be repositioned to create new interior layouts based on different needs and space usage. Steel-built structures can cater for such changes. Non-composite steel beams can be made composite with the existing floor slab, cover plates added to the beams for increased strength, beams and girders easily reinforced and supplemented with additional framing or even relocated to support changed loads. Steel framing and floor systems also allow easy access and alterations to existing electrical wiring, computer networking cables and communication systems.
Less columns, more open space	Steel sections provide an elegant, cost-effective method of spanning long distances. Extended steel spans can create large, open plan, column free internal spaces, with many clients now demanding column grid spacing over 15 metres. In single storey buildings, rolled beams provide clear spans of over 50 metres. Trussed or lattice construction can extend this to 150 metres. Minimising the number of columns makes it easier to subdivide and customise spaces. Steel-built buildings are often more adaptable, with greater potential for alterations to be made over time, extending the lifetime of the structure.

Endlessly recyclable	When a steel-framed building is demolished, its components can be reused or circulated into the steel industry's closed-loop recycling system for melt down and repurposing. Steel can be recycled endlessly without loss of properties. Nothing is wasted. Steel saves on the use of natural raw resources since around 30% of today's new steel is already being made from recycled steel.
Added fire resistance	Extensive testing of structural steelwork and complete steel structures has provided the industry with a thorough understanding of how steel buildings respond to fire. Advanced design and analysis techniques allow precise specification of fire protection requirements of steel-framed buildings, often resulting in significant reductions in the amount of fire protection required.
Earthquake resistance	Earthquakes are unpredictable in terms of magnitude, frequency, duration, and location. Steel is the material of choice for design because it is inherently ductile and flexible. It flexes under extreme loads rather than crushing or crumbling. Many of the beam-to-column connections in a steel building are designed principally to support gravity loads. Yet they also have a considerable capacity to resist lateral loads caused by wind and earthquakes.
Aesthetics, meet function	Steel's slender framing creates buildings with a sense of openness. Its flexibility and malleability inspire architects to pursue and achieve their aims in terms of exploring distinctive shapes and textures. These aesthetic qualities are complemented by steel's functional characteristics that include its exceptional spanning ability, dimensional stability over time, its acoustic noise dampening abilities, endless recyclability and the speed and precision in which it is manufactured and assembled onsite with minimal on-site labour.
More usable space, less material	Steel's ability to maximise space and internal width with the thinnest shell possible means thinner, smaller structural elements are achievable. Steel beam depths are around half that of timber beams, offering greater usable space, less materials and lower costs compared with other materials. Wall thicknesses can be thinner because steel's strength and excellent spanning capacity means there's no need to build solid, space-consuming brick walls. This can be particularly relevant for heavily constrained sites, where steel's space-saving properties can be the key to overcoming spatial challenges.
Lighter and less impacting on the environment	Steel structures can be significantly lighter than concrete equivalents and require less extensive foundations, reducing the environmental impact of the build. Less and lighter materials means they are easier to move around, reducing transportation and fuel use. Steel pile foundations, if required, can be extracted and recycled or reused at the end of a building's life, leaving no waste material on site. Steel is also energy efficient, as heat radiates quickly from steel roofing, creating a cooler home environment in hot climate areas. In cold climates, double steel panel walls can be well insulated to better contain the heat.

1.1 Various types of steel in the construction

There are various products made from steel that are used in the construction industry. Each has their own unique properties and therefore specific uses in building and other construction projects. The main seven types include structural, rebar, alloy, mild, stainless, tool, and light gauge. Below is the description of each of these seven main steel types used in the construction activities which is extracted from (Tork Media LLC)[1]:

[1] Tork Media LLC. 2019. Hard as Steel! The 7 Types of Steel to Use in Construction. https://www.rushprnews.com/2019/01/13/hard-as-steel-the-7-types-of-steel-to-use-in-construction/

Structural steel is durable and strong. It can be transformed into any shape including but not limited to I-Beam, L shape, T shape, and Z shape. This type of steel can be constructed in no time on the construction site. High-rise buildings and skyscrapers are constructed using structural steel, but it's also used for garages and large agricultural buildings.

Rebar Steel is also known as reinforcing steel. Rebar is made from different alloys and grades of steel. Stainless steel rebar is rust resistant and used in poured concrete driveways and construction of buildings. It's commonly used as a tension device for reinforced concrete structures. Rebar steel is made from carbon steel. It's also used as a tensioning device to reinforce other masonry structures. This type of steel is durable, resistant and stiff. Rebar is very useful because of its recyclable tendencies.

Rebar Steel has had small amounts of one or more alloying elements such as manganese, silicon, nickel, copper, chromium, titanium, and aluminium added to it. This mix gives out properties that aren't found in regular carbon steel. Alloy steel is usually more responsive to heat and mechanical treatments than carbon steel. Alloy steel is pretty popular because of their ease of processing, good mechanical properties, and availability. Alloy steels are broken down into Low alloy steels and High alloy steels.

Mild Steel is also known as plain carbon steel. It is steel with carbon content up to 2.1% by weight. Mild steel is also used in steel building constructions. It is durable and strong and makes for a sturdy establishment. Mild steel is also very flexible which does not allow it to crack when its bent. Due to its strength, it's more suitable for buildings. This type of steel can withstand earthquakes making it very popular in earthquake-prone areas.

Stainless Steel is a steel alloy but with increased corrosion resistance compared to alloy steel. Common ingredients mixed with stainless steel include chromium, nickel, or molybdenum. Stainless steel contains chromium at 10% or more by weight. This extra chromium gives steel its unique corrosion resisting properties. The chromium content allows the formation of a rough corrosion-resisting chromium oxide film on the surface. If the film is damaged mechanically or chemically its self-healing as long as oxygen is present. Many kitchen appliances are made from stainless steel. Food and handling processing, medical instruments, and hardware are also made from stainless steel. There are more than 60 grades of stainless steel.

Tool Steel is extremely hard and usually used to form other metal products. Different tool applications include cutting applications, mold-making applications, impact applications (like hammers) and knives. Tool steel comes in various shapes including square bar, round bar, and flat bar just to name a few. Six groups of tool steels include water-hardening, shock-resistant, hot-work, special purpose, cold-work, and high-speed.

Light Gauge Steel is known to offer a range of benefits due to its unique lightweight characteristic such as fast construction, safe to work, cost-effective, easy to handle during fabrication, highly sustainable method of construction and its production is energy efficient. Light gauge steel is used in modular construction, storage, light-steel framed buildings, and loads from walls above and resisting lateral wind loads.

2 STEEL INDUSTRY OVERVIEW

Structural steel fabricating industry has derived solid demand from the key building markets over the past five years, although declining demand from the non-building and mining infrastructure markets has negatively affected the industry's performance. The constant threat of competition from low-priced imports has also limited industry revenue growth over the period. Industry revenue is expected to decline at an annualised 1.5% over the five years through 2019-20 to total $6.1 billion. This performance mainly reflects the deterioration in domestic demand for structural steel products over the same period. Domestic demand has fallen faster than industry revenue, as imports have declined rapidly since 2014-15. Falling demand for structural steel components for large-scale resource developments, such as LNG processing plants in northern Australia, has driven this decline in imports.

Reduced investment in large-scale apartment developments and declines in several key infrastructure markets are expected to cause industry revenue to contract by 4.3% in 2019-20. Declining demand for steel products from multi-storey office, hotel and retail store construction projects is constraining the industry's performance. However, major road construction projects, such as WestConnex in Sydney and the West Gate Tunnel project in Melbourne, continue to be a stable source of demand for fabricated structural steel products.

The industry's performance is forecast to strengthen over the next five years as investment in residential building construction and several key infrastructure markets recovers. However, a further decline in demand from the residential building market over the short term is expected to limit demand for structural steel. Domestic demand is forecast to grow at an annualised 0.8% over the next five years, to total $7.9 billion, although the industry is projected to gradually lose market share to low-cost imports. Industry revenue is anticipated to rise at an annualised 0.5% over the five years through 2024-25, to total $6.3 billion.

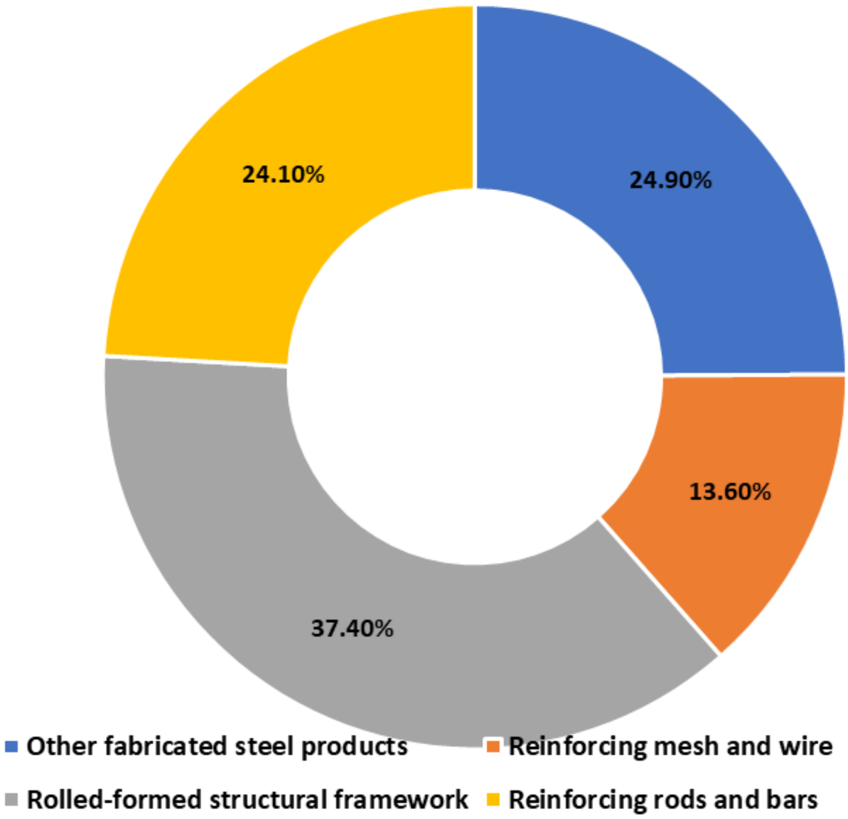

Figure 1. The industry products and services segmentation. Source: Kelly (2019)[2]

[2] Kelly, A. 2019. Structural Steel Fabricating in Australia. Australia Industry (ANZSIC) Report C2221.

The key economic drivers for the industry are directly related to the demand from (residential and non-residential) construction activities and beverage manufacturing (Table 2). Similarly, the main demand industries include those related to construction activities.

Table 2. Key drivers and the major industries dealing with timber wholesaling (demand & supply).

Key Economic Drivers	Demand Industries	Supply industries
Demand from residential building construction	House Construction in Australia	Iron Smelting and Steel Manufacturing in Australia
Demand from non-residential building construction	Multi-Unit Apartment and Townhouse Construction in Australia	
Demand from road and bridge construction	Road and Bridge Construction in Australia	
Domestic price of iron and steel	Heavy Industry and Other Non-Building Construction in Australia	
Trade-weighted index	Structural Steel Erection Services in Australia	
Demand from heavy industry and other non-building construction	Commercial and Industrial Building Construction in Australia	

Source: IBISWorld 2019[2]

2.1 Major producers in Australia

In Australia, the major players of the steel fabrication market (2015-2020) produce 45% of annual steel product[2]. The steel market is dominated by two manufacturers namely " BlueScope Steel Limited (23.9%)", and " Infrabuild Trading Pty Ltd (21.1%)". The rest of the market is supplied by small to medium-sized firms which hold a small share of the market. These steel fabrication firms supply a range of products. Most firms operate in narrow state-based markets, although several medium- to large-scale businesses have operations spanning several states and a range of products.

2.2 Demand determinants

The key demand determinants in this industry include demand from residential, non-residential building, heavy industry and other non-building and road and bridge construction. The followng are the description for each of determinant:

2.2.1 Demand from residential building construction

Investment in residential building construction, including single-unit housing, multi-unit apartments and renovations and repairs, drives sales of structural steel products. High-rise apartment developments represent a particularly important market for industry products such as reinforcing steel, girders, plates, rods, joists and scaffolding. Demand from residential building construction is expected to decline in 2019-20 due mainly to the sharp reduction in apartment construction as a result of the recent completion of major high-rise developments and oversupply conditions in some urban markets. This trend is anticipated to limit sales of structural steel building products in 2019-20.

2.2.2 Demand from non-residential building construction

Constructing non-residential buildings, such as multi-storey office developments, large industrial buildings and shopping centres, requires high volumes of structural steel products. Increased investment in commercial and industrial building developments has directly boosted industry sales over the past five years. Demand from non-residential building construction is expected to decrease during 2019-20, reflecting the winding back of investment on some major commercial building projects. However, despite the scaling back of activity in this market, continued work on major office and hotel projects is expected to support growth for some suppliers

2.2.3 Demand from heavy industry and other non-building construction

Heavy industry and other non-building infrastructure projects require large volumes of structural steel products. Robust investment in mining infrastructure and other infrastructure developments increased demand from this market to a record peak in 2013-14, but it has sharply contracted over the past five years. Firms are continuing to wind back investment in major developments such as the LNG processing plants in northern Australia. Demand from heavy industry and other non-building construction is expected to decline further during 2019-20, which poses a significant threat to the industry's short-term performance.

2.2.4 Demand from road and bridge construction

Construction firms use large quantities of steel components to construct bridges, tunnels and road pavements. Public and private investment, particularly in large-scale toll road and tunnel developments, influences demand from this construction market. Demand from road and bridge construction is expected to maintain strong growth during 2019-20, lifting activity to historically high levels with work on major road projects. This trend provides an opportunity for the supply of structural steel products, such as reinforcing mesh of welded steel and reinforcing rods.

2.2.5 Domestic price of iron and steel

Steel is the industry's primary material input and therefore increases in the price of steel raise production costs. Industry operators tend to pass these increases on to consumers through higher prices, which increases industry revenue. However, rising steel input prices can erode profit margins for structural steel producers if price rises cannot be passed on in full. The domestic price of iron and steel is expected to decrease during 2019-20 due to a sharp fall in the world price of iron ore.

2.2.6 Trade-weighted index

The industry is exposed to substantial import competition. Competitive pressures typically increase when the Australian dollar appreciates against its major trading partners. Industry sales tend to deteriorate as the Australian dollar appreciates, as local companies become less competitive against imports. The Australian dollar has depreciated over the past five years, providing some relief for local manufacturers. The continued decline in the trade-weighted index during 2019-20 may improve the industry's cost competitiveness in international markets.

2.3 Raw materials

The steel industry is dependent on a sufficient, dependable and reasonably priced supply of raw materials. Two tonnes of raw materials are required to produce one tonne of steel. Key raw materials needed in steelmaking include iron ore, coal, limestone and recycled stee. The following are the description of these key mateirals that are extracted from WorldSteel Association (2019)[3]:

Iron ore: Steel is an alloy consisting mostly of iron and less than 2% carbon. Iron ore is, therefore, essential for the production of steel, which in turn is essential in maintaining a strong industrial base. 98% of mined iron ore is used to make steel. Iron is one of the most abundant metallic elements. Its oxides, or ores, make up about 5% of the earth's crust. Average iron content for high-grade ores is 60% to 65%, after taking into account other naturally-occurring impurities.

The majority of iron ore is mined in Brazil, Australia, China, India, the US and Russia. Australia and Brazil together dominate the world's iron ore exports, each having about one-third of total exports. Worldwide iron ore resources are estimated to exceed 800 billion tonnes of crude ore, containing more than 230 billion tonnes of iron. Australia consolidated its position as the main supplier of steelmaking materials with iron ore exports growing from about 150 Mt to 800 Mt

Coal and coke: Coking coal is a key raw material in steel production. As iron occurs only as iron oxides in the earth's crust, the ores must be converted, or 'reduced', using carbon. The primary source of this carbon is coking coal. Coke, made by carburising coking coal (i.e. heating in the absence of oxygen at high temperatures), is the primary reducing agent of iron ore. Coke reduces iron ore to molten iron saturated with carbon, called hot metal. Around 1 billion tonnes of metallurgical coal are used in global steel production, which accounts for around 15% of total coal consumption worldwide .

Coal reserves are available in almost every country worldwide, with recoverable reserves in around 80 countries. Although the biggest reserves are in the US, China, Russia, Australia and India, coal is actively mined in more than 70 countries. About 30% of coal can be saved by injecting fine coal particles into the blast furnace, a technology called Pulverised Coal Injection (PCI). One tonne of PCI coal used for steel production displaces about 1.4 t of coking coal.

Limestone: it is the most used flux, is a sedimentary rock, usually white, varying from hard and compact to soft and friable.

Recycled steel: Steel products naturally contribute to resource conservation through their lightweight potential, durability and recyclability. At the end of a product's life, steel's 100% recyclability ensures that the resources invested in its production are not lost and can be infinitely reused. Due to its magnetic properties, steel is easy to separate from waste streams, enabling high recovery rates and avoiding landfills. Some steel products contain up to 100 % recycled content. Recycled steel is a key input needed for all steelmaking process routes. EAFs can be charged with up to 100% of recycled steel and basic oxygen furnaces with approximately 30%.

2.4 Products overview

Figure 2 displays various applications of steel in the construction industry. In this report in total 40 different steel products are identified.

[3] WorldSteel Association. 2019. Fact sheet: steel and raw materials. https://www.worldsteel.org/en/dam/jcr:16ad9bcd-dbf5-449f-b42c-b220952767bf/fact_raw%2520materials_2019.pdf

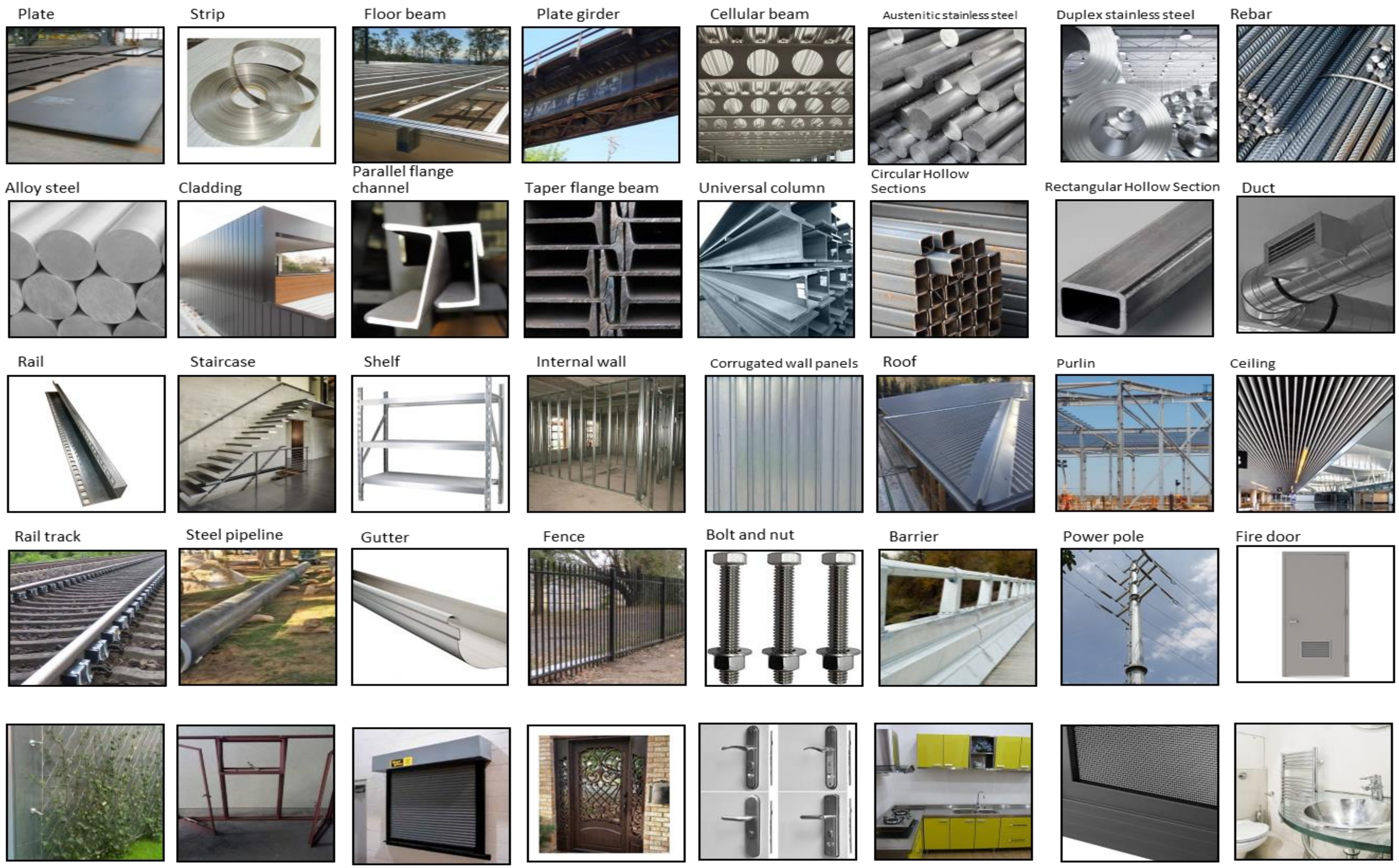

Figure 2. Various applications of Steel products in the construction industry

2.5 Manufacturing process

Steel is an alloy produced via two main methods: basice oxygen furance (primary) and electric arc furance (secondary). The following are the description of these two common methods[4]:

Basic oxygen furnace (BOF): the most commonly applied process for steelmaking is the integrated steelmaking process via the Blast Furnace. In the basic oxygen furnace, the iron is combined with varying amounts of steel scrap (less than 30%) and small amounts of flux (Figure 3). A lance is introduced in the vessel and blows 99% pure oxygen causing a temperature rise to 1700°C. The scrap melts, impurities are oxidised, and the carbon content is reduced by 90%, resulting in liquid steel.

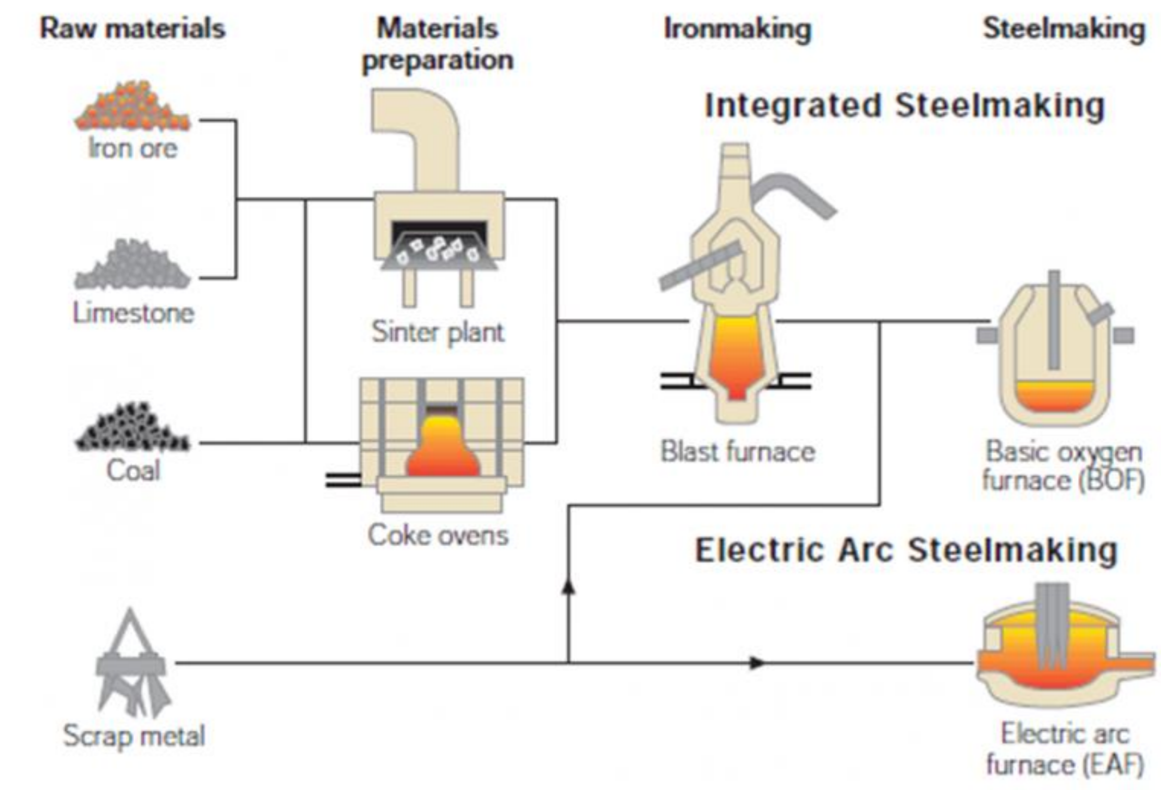

Figure 3. The typical steelmaking processes
Source: Steel construction encyclopedia (2019)[5]

Other processes can follow – secondary steelmaking processes – where the properties of steel are determined by the operation of the blast furnace demands the highest quality of raw materials – the carbon content of coke, therefore, plays a crucial role in terms of its effect in the furnace and on the hot metal quality. A blast furnace fed with high-quality coke requires less coke input, results in higher addition of other elements, such as boron, chromium and molybdenum, amongst others, ensuring the exact specification can be met—optimal quality hot metal and better productivity. Around 0.6 tonnes (600 kg) of coke produces 1 tonne (1000 kg) of steel, which means that around 770 kg of coal is used to produce 1 tonne of steel through this production route. BOFs currently produce about 74% of the world's steel.

[4] World Coal Association. 2019. How is steel produced. https://www.worldcoal.org/coal/uses-coal/how-steel-produced
[5] Steel Construction Encyclopedia.2019. Recycling and reuse. https://www.steelconstruction.info/Recycling_and_reuse

Electric arc furnaces (EAF): The EAF process, or mini-mill, does not involve iron-making. It reuses existing steel, avoiding the need for raw materials and their processing. The furnace is charged with steel scrap; it can also include some direct reduced iron (DRI) or pig iron for chemical balance. The EAF operates on the basis of an electrical charge between two electrodes providing the heat for the process. The power is supplied through the electrodes placed in the furnace, which produce an arc of electricity through the scrap steel (around 35 million watts), which raises the temperature to 1600˚C, melting the scrap. Any impurities may be removed through the use of fluxes and draining off slag through the taphole.

Electric arc furnaces do not use coal as raw material, but many are reliant on the electricity generated by coal-fired power plant elsewhere in the grid. Around 150 kg of coal is used to produce 1 tonne of steel in electric arc furnaces.

3 REGULATIONS, POLICIES, AND GUIDELINES

Legislation of steel waste management occurs at the jurisdictional level. As a result, there are various policies and requirements for steel waste in Australia. However, the inconsistencies in these jurisdictions are regarded as a challenge for successful management of steel waste.

The Australian Steel Stewardship Forum (ASSF) has developed a sustainability certification scheme for Australian 'ResponsibleSteel' (*http://www. responsiblesteel.org/*). In 2019, ASSF published the first version of ResponsbileSteel[6], in which 12 principles for steel production in a responsible manner are outlined. Principle 9 states that this scheme certifies sites that prevent and reduce emissions and effluents that have adverse effects on communities or the environment, manage waste according to the waste management hierarchy and take account of the full life cycle impacts of waste management options. The objective of this principle is to find the most appropriate waste management option, making sure that waste is avoided or recovered where reasonably possible, and disposed of in a responsible manner.

[6] The Australian Steel Stewardship Forum.2019. ResponsbileSteel Standard Version no. 1. https://www.responsiblesteel.org/ wp-content/uploads/2019/11/ResponsibleSteel_Standard_v1-0.pdf

4 STEEL WASTE GENERATION

4.1 How much steel waste is generated?

The latest steel waste data is for period 2016-17[7] and presented in Table 3. The available waste data for steel is incomplete and does not represent the entire steel waste management across Australia. According to the available data in the study period, 3,822,990 tonnes of steel waste was generated in Australia. Among the state and territories, the largest volume was generated in NSW (1,345,349), Vic (925,563) and Qld (703,502). Except for SA with 3,155 tonnes of landfilled steel waste, other states did not report their disposal rate. From data reported in Table 3, it is not possible to find out the volume of steel waste generated in C&D stream.

Table 2. Steel waste generation and fates in Australia

	Waste Generation		Waste Landfill		Waste Recycling	
State	**C&D**	**TOTAL**	**C&D**	**TOTAL**	**C&D**	**TOTAL**
ACT	n/a	20,308	n/a	n/a	n/a	20,308
NSW	n/a	1,345,349	n/a	n/a	458,508	1,345,349
NT	n/a	58	n/a	n/a	0	58
QLD	n/a	703,502	n/a	n/a	0	703,502
SA	2,328	275,405	2,328	3,155	27,500	272,250
TAS	n/a	39,753	n/a	n/a	0	39,753
VIC	n/a	925,563	n/a	n/a	116,920	925,563
WA	n/a	513,052	n/a	n/a	109,248	513,052
TOTAL	2,328	3,822,990	2,328	3,155	712,176	3,819,835

Source: Department of Environment and Energy. 2016-17 [6]
Note: *the values for waste generation is the result of summing waste landfilling and recycling values.*

4.2 Types of steel waste

Steel products are inherently low waste through all stages of the building life cycle; production, construction and end-of-life of buildings. Steel products are typically pre-engineered to the correct dimensions; hence, there is no site waste at construction sites. The quality of steel construction products and the dimensional stability of the material itself generate few defects and consequently minor site waste. However, there is still some waste generated in the construction industry, notably during demolition activities, including the following:

Manufacturing– Steel slag, a by-product of steel making, is generated during the separation of the molten steel from impurities in steelmaking furnaces.

[7] Department of Environment and Energy. 2019. National Waste Report Data. https://www.environment.gov.au /protection/ waste-resource-recovery/national-waste-reports/national-waste-report-2018

Deconstruction–Steel waste from the deconstruction of buildings and infrastructures such as bridges. A survey in the UK[8] listed the main steel waste products are heavy structural sections/tubes, rebar, steel piles. Light structural steel, profile steel cladding, internal light steel, and others.

Moulds – Parts that are already worn out and cannot be renewed or reused

Off cuts– Waste generated during the application of steel reinforcing bars

[8] Sansom, M. & Avery, N. Briefing: Reuse and recycling rates of UK steel demolition arisings. Proceedings of the Institution of Civil Engineers-Engineering Sustainability, 2014. Thomas Telford Ltd, 89-94.

5 STEEL WASTE MANAGEMENT

The aim of this section is to provide an insight into the sustainable management of steel waste through various opportunities that emerge throughout the steel lifecycle. It also discusses the various waste management methods that are supplemented by some case studies that showcasing success story in sustainable steel waste management. Steel construction products are inherently low waste products through all phases of the design, production, construction, and deconstruction process. Designers and specifiers can be confident that, by choosing steel construction products and systems, material resources are optimised, waste is minimised, and recycling is maximised[7].

5.1 Waste during manufacturing

By-products from iron and steel making, including sludges, slags, and dust, are beneficially used by the construction industry in a range of products including roadstone, rail ballast, engineering construction fills, lightweight aggregate and as a substitute for Portland cement. During component manufacture, computer-controlled, fully or semi-automated production lines ensure that wastage of steel is minimised. The typical wastage rate for fabricating structural steel products is just 4%, and any offcuts, trimmings, swarfe, etc. from the production process are 100% recycled into new steel (Figure 3)[9].

5.2 Waste reduction opportunities during the design, planning, and contract

To date, the focus of C&D waste reduction has been mainly on-site waste management practice. However, the best opportunities for improving materials resource efficiency in construction projects occur during the design stage[10]. Implementing these opportunities can provide significant reductions in cost, waste and carbon. There are five key principles that design teams can use during the design process to reduce waste. These principles are based on extensive consultation, research and work carried out by WRAP directly with design teams[8]. They are summarised in Table 4 together with questions the design team should address to design out waste.

Table 3. Design opportunities to reduce steel waste.

Opportunity	Description	Questions
Design for reuse and recovery	Design for reuse of material components and/or entire buildings has considerable potential to reduce the environmental burdens from construction. Much of this is common sense as, with reuse, the effective life of the materials is extended and thus annualised burdens are spread over a greater number of years.	▪ On previously developed sites, can materials from the demolition of the building be reused in the design? ▪ Can reclaimed products or components be reused? ▪ When materials are reused, can they be reused at their highest value? ▪ Can any excavation materials be reused? ▪ Can cut and fill balance be achieved? How can it be optimised to avoid removal of spoil from the site?

[9] Steel Construction Encyclopedia. 2019. Construction and demolition waste.
https://www.steelconstruction.info/ Construction and demolition waste#Waste in steel construction
[10] WRAP. 2010. Designing out Waste Tool for Buildings (DoWT-B).
http://www.wrap.org.uk/sites/files/wrap/DoWT-B%20User%20Guide.pdf

Design for off-site construction	Off-site construction is one of a group of approaches to more efficient construction, sometimes called Modern Methods of Construction (MMC) that also include prefabrication and improved supply chain management. Experience shows that the choice of off-site construction can have a significant influence on initial design considerations and therefore, should be considered during the early project stages.	▪ Can the design or any part of the design be manufactured off-site? ▪ Can site activities become a process of assembly rather than construction?
Design for materials optimisation	Good practice in this context means adopting a design approach that focuses on materials resource efficiency so that less material is used in the design, i.e. lean design, and/or less waste is produced in the construction process, without compromising the design concept. Three main areas offer significant potential for waste reduction. ▪ Minimisation of excavation ▪ Simplification and standardisation of materials and component choices ▪ Dimensional coordination.	▪ Can the design, form and layout be simplified without compromising the design concept? ▪ Can the design be coordinated to avoid/minimise excess cutting and jointing of materials that generate waste? ▪ Is the building designed to standard material dimensions? ▪ Can the range of materials required be standardised to encourage reuse of offcuts? ▪ Is there repetition & coordination of the design, to reduce the number of variables and allow for operational refinement, e.g. reusing formwork?
Design for waste efficient procurement	Designers have considerable influence on the construction process itself, both through specification as well as setting contractual targets, prior to the formal appointment of a contractor/constructor. Designers need to consider how work sequences affect the generation of construction waste and work with the contractor and other specialist subcontractors to understand and minimise these. Once work sequences that cause site waste are identified and understood, they can often be ‘designed out.	▪ Has research been carried out to identify where on site waste arises? ▪ Can construction methods that reduce waste be devised through liaison with the contractor and specialist subcontractors? ▪ Have specialist contractors been consulted on how to reduce waste in the supply chain? ▪ Have the project specifications been reviewed to select elements/components/materials and construction processes that reduce waste?
Design for deconstruction and flexibility	Designers need to consider how materials can be recovered effectively during the life of the building when maintenance and refurbishment are undertaken or when the building comes to the end of its life. A range of alternative construction methods is likely to be	▪ Is the design adaptable for a variety of purposes during its life span? ▪ Can building elements and components be maintained, upgraded or replaced without creating waste? ▪ Does the design incorporate reusable/recyclable components and materials?

	suitable for the design for deconstruction and flexibility. Generally, those methods that facilitate easy disassembly at the end of the design/service life to improve the potential for reuse and/ or recyclability should be selected in preference to the more contiguous structural systems.	▪ Are the building elements/components/materials easily disassembled? ▪ Can a Building Information Modelling (BIM) system or building handbook be used to record which and how elements/components/materials have been designed for disassembly?

Source: WRAP (2010)[8]

5.3 Reducing waste during the procurement

Application of technologies such as BIM during the procurement phase can significantly reduce steel waste. These technologies improve quantity take-off practices and procurement documentation leading to a precise estimation of steel required for a construction project. Procurement documentation should include a full analysis of quality, price, flexibility and other conditions (e.g. location, service level, etc.)(Wang and Wang, 2010).

5.4 Reducing waste during transportation & delivery

Steel products are delivered to the construction site pre-engineered to the correct dimensions; consequently, there is little to no waste during transportation[7].

5.5 Reducing waste during construction

Steel products are delivered to site with minimal packaging. Packaging comprises mainly timber pallets and bearers and plastic or metal strapping. Timber packaging is generally reused by the haulage company making site deliveries, and the strapping is either recycled or reused. Off-site construction can contribute to steel waste minimisation. Technologies used for offsite manufacture and prefabrication include light gauge steel framing systems and modular and volumetric forms of construction which offer great potential for improvements to the efficiency and effectiveness of construction[7].

5.6 Reducing waste during demolition and renovation

The majority (about 90%) of metals recovered from the C&D sector comes from commercial demolition sites. Of this material, up to 95% is steel, and the remaining materials (about 5 %) are non-ferrous metals. This non-ferrous component mostly includes aluminium (1 to 2%), stainless steel and copper piping or wire[11]. Ferrous metals like steel can be easily recovered from the waste stream using relatively inexpensive magnets. Increase in the metal scrap collection is traditionally following demolition activities in the construction industry (Figure 1)[12].

[11] Edge Environment Pty Ltd for the department.2012. Construction and Demolition Waste Guide - Recycling and Re-Use Across the Supply Chain. www.environment.gov.au/system/files/resources/b0ac5ce4-4253-4d2b-b001-0becf84b52b8/files/case-studies.pdf

[12] Industry Commission. 1991. Working paper no. 1. An analysis of the factors affecting steel scrap collection.

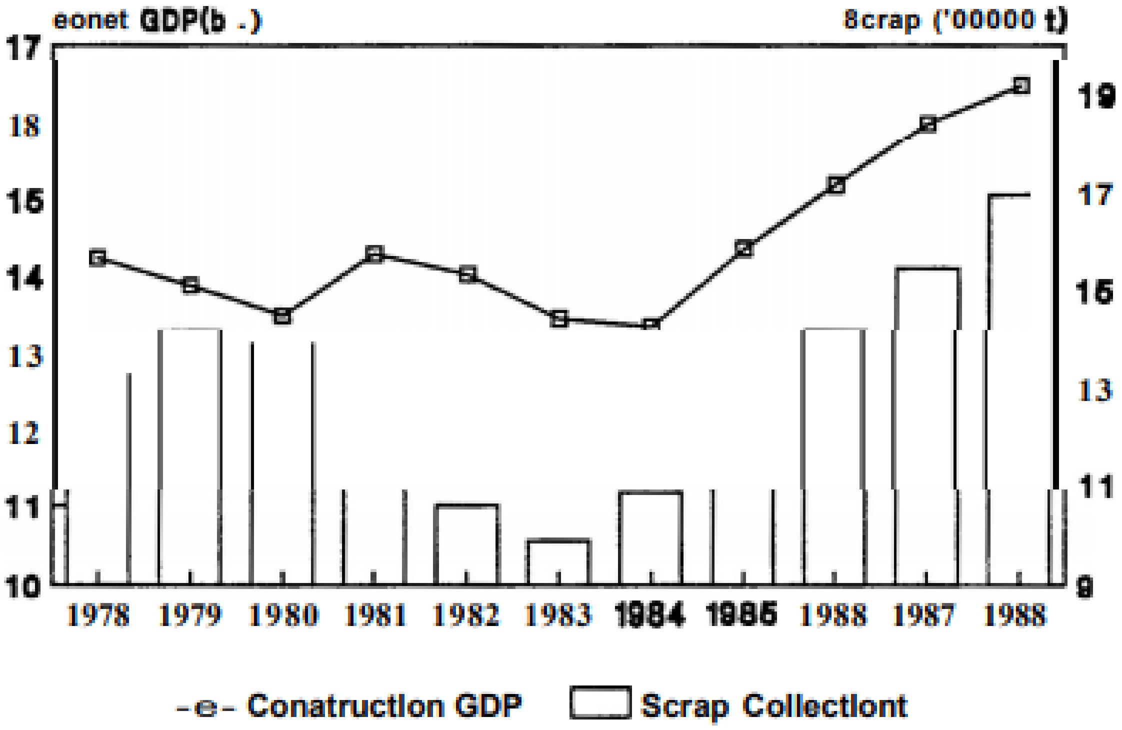

Figure 4. Construction activity level and scrap collection in Australia between 1978-1998
Source: Industry Commission (1991)[10]

When a building is deconstructed, the ease with which steel construction products can be reclaimed, coupled with the economic value of scrap steel, and all steel is recovered and either reused or recycled. In fact, heavy materials such as steel can be readily recovered. Furthermore, steel is one of the few magnetic metals[1] and is easy to separate from waste streams.

Hyder (2012)[13] reported that when demolition activities were high, and prices for metals were strong, demolition companies would bring their materials for recycling to the key metal recyclers. However, when there was a downturn in both activity and metal prices, it was suggested that the demolition companies were more likely to stockpile the metals if they could and wait for improved commodity prices.

The issue with demolition is that reinforced steel used in some structures is mixed with concrete. In the demolition phase, there can be a ratio of 80% concrete to 20% steel. Demolition companies recycle the concrete. But according to estimations generally, the recycled steel has about 10% concrete (contamination) remaining with the steel[11].

5.7 Reducing waste through reusing

Reuse offers even greater environmental advantage than recycling since there are few to no environmental impacts associated with reprocessing waste recovery (recycling and upcycling). For instance, reusing a steel beam in its existing form is better than remelting it and rolling a new steel beam, i.e. the energy used to remelt the beam is saved**[14]**. Reuse of structural steel can take place in industries such as agriculture where the aesthetic aspect is of less concern. A recent survey in the UK

[13] Hyder. 2012. Construction and demolition waste status report. Management of construction and demolition waste in Australia

[14] SteelConstruction.info. 2019. Recycling and reuse. https://www.steelconstruction.info/Recycling_and_reuse

showed that the steel recovery rate is 96% of which 5% belongs to reusing (Sansom and Avery, 2014). The main technical, logistic and cost barriers for reusing structural steel are tabulated below

Table 4. Barries towards reusing of structural steel

Technical	Logistical	Costs
• Lack of standardisation of components • Ensuring and warranting the performance of reused components • Lack of detailed knowledge of the product's properties and in-use history • Quality assurance of reused products • Robustness of products in the deconstruction process, i.e. many lighter products do not survive the deconstruction process intact • Practicalities of economic deconstruction including deconstructing composite components	• Assured availability of supply • Demolition programmes are too short to enable contractors to deconstruct buildings • Sufficient storage space for recovered products • Deconstruction, as opposed to demolition, has significant impacts on the health and safety precautions required	• Lack of commercial drivers for reuse • Cost of storage, cataloguing, refurbished products, etc. • Cost of testing to verify and guarantee properties • Client expectation that 'second-hand' products should be cheaper than new ones • An additional cost of deconstruction over (faster) demolition (as opposed to demolition which is generally undertaken using remote machinery)

Source: *SteelConstruction.info*

Case Study- Honda central receiving building[15]

Originally erected on Honda's Swindon site in 2001, this 927m2 steel-framed warehouse building was dismantled in 2004 and put into storage. In September 2005, the structure was re-erected, at a different location on the same Swindon site, as a new Central Receiving Area for all incoming components delivered to Honda UK.

Figure 4. Honda central receiving building
Source: Caunton Engineering

[15] SteelConstruction.info. 2018. Honda central receiving building https://www.steelconstruction.info/Honda_central_receiving_building

All the main frame structural steelwork was reused including the column base plates, bracing and cold-rolled secondary steel. Unfortunately, it was not possible to reuse the original cladding mainly because of the change of use of the building and changes to the Building Regulations. However, the composite steel cladding was carefully dismantled and reused as an internal noise abatement lining by the steelwork contractor Caunton Engineering, near Nottingham. The dismantled steel structure was re-erected in just one week! The condition of the steelwork was assessed by the coating manufacturer Sherwin-Williams Protective & Marine Coatings, cleaned and then repainted to Honda's specification for the newly erected building. A new built-up steel cladding system, meeting the needs of the Building Regulations at that time, and Honda's corporate requirements, was installed to the primary structure.

5.8 Waste recovery (recycling and upcycling)

Steel is the most recycled material in the world, with about 670 Mt recycled in 2017, including pre- and post-consumer scrap. Steel is one of the few magnetic metals and is easy to separate from waste streams. By sector, global steel recovery rates are estimated at least 85% for construction[3]. Any stainless steel item is currently made up of 60% recycled steel.

Recycled steel (scrap) can be collected from excess material in steel facilities and foundries (home scrap) or downstream production processes (industrial scrap) and from discarded products (obsolete scrap). Recycling steel waste accounts for significant energy and raw material savings: over 1,400 kg of iron ore, 740 kg of coal, and 120 kg of limestone are saved for every 1,000 kg of steel scrap made into new steel[3].

The availability of home and industrial scrap is closely related to current domestic steel production levels while the availability of obsolete scrap is closely related to levels of past steel production, average product lives and efficient recycling programmes. In Australia, according to the latest data[6,] which is not complete, the recycling rate of steel waste is almost 100% (Table 5). In 2016-17 the amount of steel waste generated in all waste streams was 3,822,990 tonnes. This volume for C&D waste stream was 712,176 tonnes.

Table 5. Steel waste recycling data in Australia

Waste recycling		
State	**C&D recycling**	**Total**
ACT	n/a	20,308
NSW	458,508	1,345,349
NT	0	58
QLD	0	703,502
SA	27,500	275,405
TAS	0	39,753
VIC	116,920	925,563
WA	109,248	513,052
TOTAL	**712,176**	**3,822,990**

While the price that recyclers pay for mixed steel scrap is highly variable, the current ballpark figure for ranges between $70 (steel) and $1100 (stainless steel) per tonne. Coupled with the value of avoided landfill disposal costs, there is a strong economic incentive to recover this material stream.

5.9 Illegal dumping and stockpiling

Generally, due to the financial value of metal scrap, it is less likely that illegal dumping and stockpiling occurs in Australia. However, there are reports showing that illegal dumping activities take place due to mismanagement. Furthermore, prices of scrap metals are always very important to the scrap recycling industry. When scrap prices are in a downward trend for a long period, recycling rates decrease with the trend and scrap metal firms struggle to make a profit[16] leading to increase in illegal dumping and stockpiling hoping for a market turnaround.

Case Study - An abandoned warehouse in Thomaston, Melbourne[17]

The warehouse in Melbourne's outer north was supposed to be filled with scrap metal and broken glass, overflow storage for nearby recycling business. It was not until the company collapsed into insolvency six months later that the warehouse doors were opened to reveal a potential health and environmental disaster on Melbourne's suburban fringe: pallets of steel drums and plastic tubs, stacked to the ceiling, filled with mercury, contaminated powders, leaking batteries, and suspected X-ray machine parts. Almost 800 containers of highly toxic material, abandoned by a company that no longer operated.

[16] Haque, T. 2019. Current scarp prices trends and analysis. The balance small businesses. https://www.thebalancesmb.com/current-scrap-prices-trends-and-analysis-2877940

[17] Mannix, L., Vedelago, C. and C. Houston. 2019. The tipping point: Illegal dumping swamps the waste industry. The Age: https://www.theage.com.au/national/victoria/the-tipping-point-illegal-dumping-swamps-the-waste-industry-20170806-gxq8m0.html

Figure 5. An abandoned warehouse in Thomaston (Melbourne) which was filled with tonnes of waste including steel waste
Source: Mannix et al. (2019)

5.10 Waste landfilling

Disposal of stainless-steel waste to landfills is not harmful to the environment but is a waste of resources. In metropolitan markets, there is likely to be very little metal from the C&D waste stream that ends up in a landfill, a source on Australian waste landfilling indicates that disposal rate is about 2.5%. Even in regional areas, where landfill fees are lower, and there may be limited metal reprocessors, indications are that scrap metal is separated from other materials and put aside at local transfer stations, resource recovery facilities and landfills, ready for collection once there is a sufficient stockpile to warrant the recovery and transport costs[11].

6 STEEL WASTE MARKET

6.1 Existing and future markets for steel waste

Stainless steel has valuable metal content - chromium and nickel. Markets for recycled stainless steel are functioning without any stimulus, and the stainless-steel industry is utilising all feasibly available recycled stainless steel.

6.2 Integrated supply chain and steel lifecycle model

Two lifecycle models for steel waste is provided below. These include EPA Victoria flow of steel and steel LowMor model.

6.2.1 EPA Victoria flow of steel model

The flow of steel in the Victorian economy is modelled in Figure 6 that is based on the period 2004/2005. In this period steel recycling represents 82% of total metal stream recycled in Victoria. From what recycled between 70-90% was used domestically and then reminder being exported[18]. The model shows that how steel waste generated during construction and demolition activities flows until it gets to landfill.

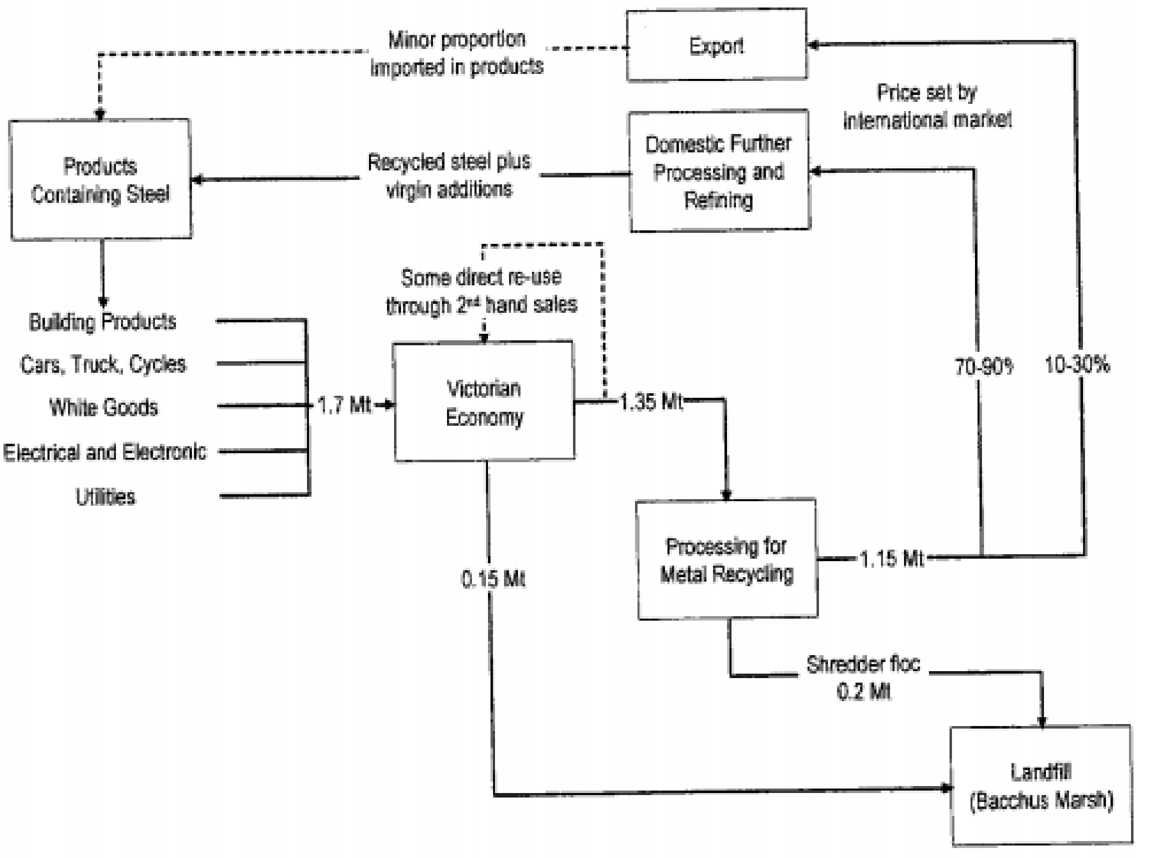

Figure 6. The flow of steel in the Victorian economy
Source: EPA Victoria (2007)

[18] EPA Victoria.2007. Impact of Landfill levy on the steel recycling sector in Victoria. 2007. http://www.aebn.net.au/info /Levy Impact_on_Steel%20_Vic_EPA_2007.pdf

6.2.2 Steel LowMor model

In this model, there are 11 points wherein steel scrap can be efficiently managed. Figure 7 depicts these opportunities and the relationships between them. In Australia, the majority of steel waste is sent back to steel fabrication manufactures to be used to produce new steel products.

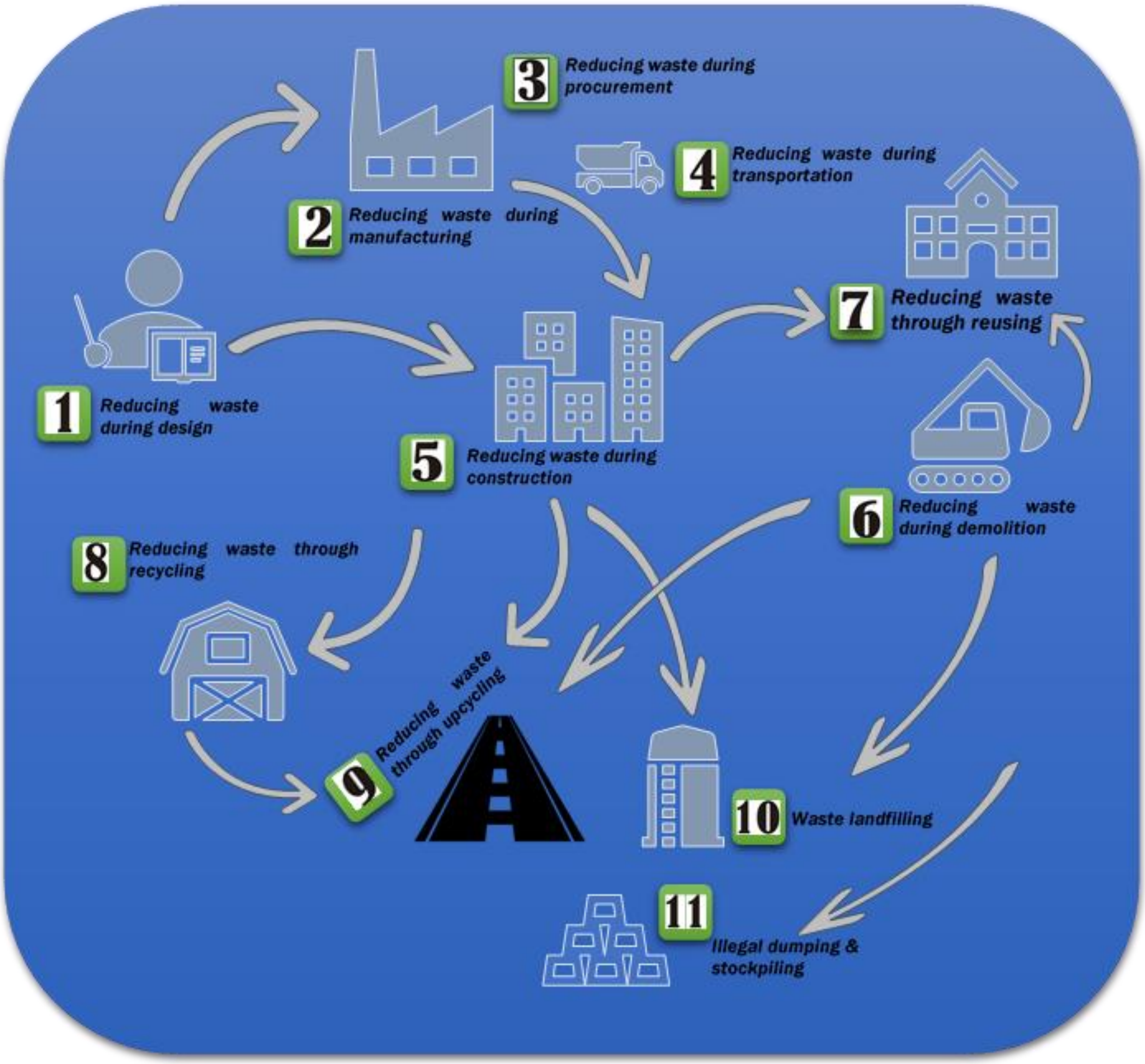

Figure 7. The integrated supply chain lifecycle model for steel waste

6.3 Barriers towards the establishment of a market for steel waste-based materials

There are several barriers identified that negatively impact the establishment of a market for steel waste-based materials. Table 6 summarises these barriers that are extracted from various Australian reports and publications.

Table 6. The main barriers identified in the establishment of recycled steel in Australia

Source	Barrier	Explanation
EPA Victoria (2007)[19]	Landfill levy	Levy on the disposal of recycling residuals reduces the competitiveness of materials sold into the market. For every \$15/tonne increase in the levy rate, an additional \$738,000 per annum cost is incurred by the steel recycling industry in Victoria.
Environment and Communications References Committee (2018)[20]	Market volatility	Steel recycling is largely affected by the price of virgin materials
Australian Council of Recycling (2015)[21]	Steel scrap is not viable	Some scrap will no longer be viable to recycle; even it is available for free Remote / Country (transport costs) • Low grade or scrap with high waste content (high waste disposal costs) • Complex (high processing costs) • Hazardous (processing and waste disposal costs) • Scrap at locations with high compliance costs or inefficient work practices

[19] EPA Victoria.2007. Impact of Landfill levy on the steel recycling sector in Victoria. 2007. http://www.aebn.net.au/info /Levy Impact_on_Steel%20_Vic_EPA_2007.pdf

[20] Environment and Communications References Committee. 2018. Never waste a crisis: the waste and recycling industry in Australia

[21] Australian Council of Recycling. 2015. Australian scrap market analysis https://www.acor.org.au/uploads/2/1/5/4/ 21549240/acor_scrap_market_analysis.pdf

6.4 Strategies towards the establishment of a market for steel waste-based materials

Together with the responses to the barriers identified above, several strategies that can facilitate the establishment of a sustainable market for steel waste-based materials are presented in this section.

Table 7. Strategies to remove barriers of recycled steel market development.

Barrier	Strategy
Landfill levy	Provision of a partial levy exemption for the steel recycling industry, better funding and grants to support the steel recycling industry, and the use of Product Stewardship programs
Australian Council of Recycling (2015)[17]	▪ Formal support for the use of recycled steel in projects across all tiers of government ▪ Offer freight subsidises to enable the delivery of recyclables to processing facilities ▪ Enforcement of anti-dumping regulations to protect the Australian steel industry from dumped Chinese steel ▪ Accelerated depreciation allowances for investment in recycling infrastructure and equipment

6.5 Economics of steel waste recovery in Australia

Generally, the scrap metal is removed from the construction site for free. However, the price that recyclers pay for mixed steel scrap is highly variable (Hyder, 2011). In 2012, a ballpark figure of $250/tonne was estimated for mixed steel scrap. Traditionally, steel waste recycling has not resulted from environmental or resource scarcity concerns nor from government requirements. In fact, those large amounts have arisen mostly from the technical requirements of steel production and commercial considerations of both steel producers and steel users[22]

Most scrap is consumed in EAFs who make billet and then roll it into products. EAFs are easy and cheap to start and stop. Cheap billet means unless scrap falls too, the best option is to turn off the EAFs and import billet instead of scrap. Scrap prices will almost certainly follow the billet price, and unless the price of billet rises, the price of scrap cannot rise. It is unlikely the price of billet will increase in the foreseeable future as iron ore prices will not rise because of new mines coming online (rather iron ore is forecast to get cheaper), local Chinese steel demand has fallen, but Chinese governments are likely to support local steel blast furnaces for both ego and political (employment) reasons, and thus Chinese blast furnaces will continue to operate and flood the world with cheap billet.

The following table (Table 8) shows the costs associated with C&D based steel waste management and recovery.

Table 8. Cost estimation of C&D-based Steel waste management and recovery

Company	Price	Pricing mechanism
Bingo	Accept steel waste at their recycling facility for free. If pick up included $350 for bin hire (12 tonnes) in NSW	Free, extra charge for pick up for up to 7 days

[22] Industry Commission. 1991. Working paper no. 1. An analysis of the factors affecting steel scrap collection.

Southern Cross Metal Recyclers	Steel waste is purchased at the range of $80-$200 p/t in Victoria Pressing steel $80 p/t (without ABN number) and $110 p/t (with ABN number) Heavy metal 110 p/t (without ABN number) and $170 p/t (with ABN number)	▪ The price includes drop off only ▪ The rate variation exists based on the type of waste and having an ABN number

Source: the rates are obtained from an online quote

6.6 Relevant industry associations

In this section, the relevant industry associations that specifically work towards better management of steel and the waste associated with steel waste are identified. These associations are to collaborate with the public sector towards recognising opportunities for further reducing, reusing and recycling steel waste in Australia. Table 9 summarises the main industry associations with a focus on steel products in Australia.

Table 9. Industry associations relevant to the management of brick waste

Associations	Vision	Website
Australian Steel Association	The ASA's primary objective is to ensure a competitive market environment in Australia for manufacturing users and converters of steel product.	https://www.steelaus.com.au/
Australian Steel Institute	ASI is the nation's peak body representing the entire steel supply chain from the manufacturing mills right through to end-users in building and construction, heavy engineering and manufacturing.	https://www.steel.org.au/
Australasian (iron & steel) Slag Association	The underlying vision of the ASA is to serve as an authoritative and credible central reference point for its stakeholders on all matters relating to the iron and steel slag industry.	https://www.sa-inc. org.au
Australian Stainless Steel Development Association	ASSDA is a non-profit industry group that aims to increase the consumption of stainless steel in Australia.	https://www.assda.asn.au/
The Australian Steel Manufacturing Research Hub	This ground-breaking initiative is a testament to the critical importance of this industry in Australia and demonstrates the value that both industry and government place in collaborative, cross-disciplinary research.	https://scholars.uow.edu.au/display/grant113823
The Steel Reinforcement Institute of Australia	SRIA is Australia's leading non-profit institute for reinforcing steel, providing the hub for knowledge, industry linkage and support.	https://www.sria.com.au/

6.7 Key stakeholder and their role in steel waste management

In this section, the role of the key stakeholders in effective market development for steel waste is provided (Table 10). The role of the stakeholders is reviewed in eleven stages with the view to reducing, recovering and diverting waste from landfilling.

Table 10. Role of various stakeholders in the reduction of steel waste

No.	Stage	Stakeholder(s)	Contributions
1	Design	Designers, construction firms, clients	• Design a new building to facilitate its re-use in the future. • Consider building standardisation to improve buildability and reduce the number of offcuts.
2	Manufacturer	Manufacturers, recyclers, suppliers	• Develop an agreement where a contractor “sells back” the recycled waste from the original material supplier. • Participate in the extended producer responsibility and product stewardship schemes.
3	Procurement and contract	Construction firms, quantity surveyors, government	• Construction firms should order steel products more accurately using the best take-off practice.
4	Transportation & delivery	Construction firms, transporters, recycling companies	• Just-in-time delivery of materials to construction to avoid damage taking place due to insufficient space for proper storage and adverse weather conditions. • Do due diligence and exercise standard work practices.
5	Construction	Construction firms, sub-contractors, waste collectors, recyclers Universities and research centres	• Consider offsite construction
6	Demolition	Demolition contractors, waste collectors, recyclers	• Consider selective deconstruction to maximising the reuse potential of its components.
7	Reusing	Construction firms, state and territory governments, EPAs and other equivalent organisations, waste collectors	• Facilitate market development • Adjust specifications in favour of more usage of steel waste-based materials in new constructions project.
8	Recycling	Recyclers, construction firms, state and territory governments, EPAs and other equivalent organisations Training courses	• Facilitate market development • Fund the development of waste recovery infrastructure • Adjust specifications in favour of more usage of recycled steel waste in new constructions project • The jurisdictional landfill levy regulations need to change in favour of further steel recycling.

9	Upcycling	Recyclers, construction firms, state and territory governments, EPAs and other equivalent organisations	• Facilitate market development. • Adjust specifications in favour of more usage of steel waste-based materials in new constructions project. • Facilitate market development. • Fund the development of waste recovery infrastructure.
10	Stopping illegal dumping and stockpiling	State and territory governments, EPAs and other equivalent organisations	• Reinforce activities that stop illegal dumping and stockpiling. • Set stricter regulations with a higher rate of penalty fees to discourage illegal dumping and stockpiling. • Strengthen controls over licensed landfill sites.
11	Landfill	State and territory governments, EPAs and other equivalent organisations	• Design appropriate landfill levy schemes to discourage steel waste landfilling.

7 RECOMMENDATIONS

The following are the recommendations for maximising the opportunities for reducing steel waste in various stages of construction and demolition activities.

- Provision of landfill levy exemption for MRT's steel recycling.
- Adjust specifications in favour of more usage of steel waste-based materials in new constructions project.
- Stabilise market volatility to ensure sustainable usage of steel waste in steel manufacturing.
- The government needs to offer freight subsidises to enable the delivery of recyclables to processing facilities.

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