Sustainability within the Materials Sector
A Futuristic Report - 2030

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Executive Summary

The aim of this report is to provide advice to organisations currently trading within the materials sector. It details the importance of adapting to sustainable practices to remain competitive in the future, particularly by 2030. It describes the current global trends in material consumption and discusses future threats and challenges expected to impact the industry. Research for this report includes a review of current practices and principal materials used, as well as the materials to be developed and implemented in the future. While it is clear that no prediction discussed for the future is certain, this report recommends that preparation towards sustainability be introduced as soon as possible.
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1.0 Introduction

Predicting the future is just as important as learning from the past. This futuristic report on sustainability within the materials sector aims to outline current trends and future directions of materials used in sustainable infrastructure. In particular, this report addresses the future solutions for sustainability in the industry; in addition to recycling and many other popular and alternative resources. Sustainable infrastructure design not only incorporates new infrastructure; it includes rehabilitation, reuse and optimisation of existing infrastructure (Arup 2012). Assumptions must be made about the context of the economic and material resources climate in 2030. The current prices for materials and resources will not suffice as parameters for futuristic predictions.

Humanity faces many challenges to progressive advancement and in order for current infrastructure to benefit future generations; it must be sustainable (Arup 2012). An evaluation of the threats and issues facing the materials sector for 2030 gives rise to the challenges forecasted which can then be addressed and managed. The challenges include: peak oil, climate change, increasing cost of water, resource depletion and infrastructure replacement. To accommodate these industry shifts, an outlook of consumer satisfaction, strategic planning for cost efficiency and legislative compliance provides a futuristic vision of sustainability within the materials sector.

All activities that humans partake in have an effect on the environment (Ashby 2009). As a result all influences to future pathways of sustainability in the materials sector need to be considered. These include: the building and construction sector, energy sector, the economy, the government, global relations, technology and environmental considerations. This report provides a snapshot of how sustainability will be used in the materials sector in 2030, under the given assumptions and subject to the influence of factors stated.
2.0 The Facts

Throughout this section various facts concerning the materials sector are discussed and supported through previous studies and data. With this supporting evidence, an educated projection can be made for the future, in particular 2030, for the material sector. This section focuses on climate change, current materials and material dependence. It looks into the trends evident in humanity and Australia’s position compared to the rest of the world.

2.1 Is Climate Change Inevitable

Many thousands of years ago climate variability forced man to wander the earth hunting and gathering for basic survival. In more recent times, over the last 1000 years or so the climate has been rather constant with only small influxes in temperature change. This trend, as shown in figure B2, has allowed man to settle which has led to the creation and development of vast civilisations. As these civilisations and now nations advance, we are becoming more aware of our influence on the environment and the need to remain sustainable. This has lead to international research and debates on whether the globe is warming or cooling as a result of our activity and what effect, if any, it will have on our future.

It can therefore be assumed that the variation of climate as experienced by the earth over the last 15,000 years will continue and be of a similar trend, as illustrated in B1. This geological scale and trend however make no correction for the influence of man, thus, more recent data needs to be considered which is presented in Appendix B –Climate Analysis. This appendix demonstrates the inevitability of climate change. The analysis looks at a range of different time scales, various data sources and the influence CO₂ emissions have on global average temperatures.
From the presented data we can conclude that the earth’s temperature is on the decline and within the next 4000 years the climate will approach a glacial period. From past climate trends, it is hypothesised that by 2030, climate has the potential to decline, having a significant impact on humanity.

2.2 Leading Infrastructural Materials

The predominant materials of today used for infrastructural development are vast and number within the thousands. They are also constantly expanding as new research discovers enhanced properties and further design applications. Given the general nature of this report and for ease of analysis we have grouped the materials into four common categories; Metals, ceramics, composites and polymers.

Appendix C discusses the world’s production of materials and then more closely at Australia’s influence, analysing both the raw materials and minerals on a global scale. Then, using the 2011 resources and energy statistics report, comparisons are made between Australia and the world usage for a limited number of predominant materials. It then focuses on analysing the four main groups of materials as mentioned above by firstly defining them, then discussing their embodied energy, usage and production globally. It concludes with comments on our carbon footprint and highlights the trends evident throughout the report.

The purpose of this analysis is to educate the reader on both the direction and magnitude of the current material sector. It is important to realize that “globally we consume roughly 10 billion \(10^{10}\) metric tons of engineering materials per year, an average of 1.5 metric tons per person” (Ashby 2013, p 18). This has grown into an extremely large dependence considering that we were living sustainably just 300 years ago.

2.3 Material Dependence
Some 300 years ago the human race was living a completely sustainable lifestyle. Today advancements in human activity have seen it become completely dependent on material resources. The question, “Is material dependence irreversible?” often arises during debates into the earth’s sustainability and ultimately jeopardising Earth’s natural environment.

History shows that the progression of ancient civilisations has been entirely dependent on their advancements with materials. During the industrial revolution and over recent years, technology has rapidly advanced leading to mass production, giving man a consumption capability far greater than that of his ancestors. This has allowed for greater population growth and a better standard of living, but, as we are coming to realize it is irreversible. In fact, “At a growth rate of just 3% per year, we will mine, process, and dispose of more “stuff” in the next 25 years than in the entire 300 years since the start of the industrial revolution” (Ashby 2013, p 32).

This has led to many investigations into sustainable infrastructure and is one of the main drivers to implement change to ‘cleaner’ engineering materials and procedures to try and counter the environmental effects associated with this dependence.

2.4 Trends in Humanity

The various trends within humanity have the ability to greatly influence our future. Appendix D presents and discusses the population growth rate over recent years of the world, and also Australia. Figure D1 and D2 demonstrate an increasing population for Australia and the World, between 1966 and 2010. Population projections for 2030 are given as 27 million for Australia and 8.6 billion for the world. These figures were obtained by extrapolating the data to the year 2030 and are considered most likely.

Another common trend seen within humanity throughout all ages is its desire to pursue financial incentives and gain. This determines essentially what decisions are made and therefore, the directions taken. It is known that if money can be gained or saved through alternative means, it is most likely to occur. This provides a challenge for any transition where finance is not key, for instance; environmentally sustainable
endeavours. There is growing awareness of the detrimental effects on the environment by human activity and a switch to more sustainable practices is being increasingly encouraged.

2.5 Australia’s Position Globally

When considering all the facts compared with the rest of the world, Australia sits in a very vulnerable position should the climate significantly change. Relying heavily on farming as well as mining exports from its large reserves, we are likely to face great changes within the future. As newer, more efficient materials are developed and the economic stability of the globe is threatened, the demand for our raw materials is likely to decrease in value. The options to recycle and develop more efficient sustainable materials, will lead the consumer to alternative products.

With technological advancements within the mining industry it can be accurately assumed that reserves will expand. This however will only buy time and the government’s position should be to support any inevitable change early, therefore adapting early. At current the government is committed to action that will safeguard our environment, sustain our society and support our economy.

Like most developed countries Australia is discouraging the release of harmful emissions into the atmosphere, educating its people on sustainable practices and designing efficient infrastructure where required.
3.0 Assumptions

In constructing a report for the future, especially that which is over a decade away, assumptions need to be made in order to achieve consistency and accurate predictions. Most relevant are those that relate to current materials and resources. Oil prices are those which hold very high importance over the coming decades, especially as its supplies and availability decreases. It is assumed that by 2020 the price of oil will increase to US$200/barrel and continue rising to US$300/barrel by 2030.

The most important resource to life on earth, water, will also increase in price. Most relevant is that of urban water and it can be assumed that its price will increase fivefold by 2030. Water for irrigation will also be effected, by 2030 the annual allocations of irrigation water will decrease by 20% on average.

It is also assumed that the price for carbon of $23/tonne has crashed to an insignificant $1/tonne by 2030. Finally, a conservative value of 1% is taken for the global population growth by 2030. In terms of Victoria, the population can be assumed to grow by approximately 1.5 million to 7.3 million in 2030.

Figure 1. Pie chart showing the distribution material usage per family.
4.0 Threats and challenges facing the Materials Sector by 2030

“Technological change has progressed at a rapid pace. Within a few decades, the world has become virtual while we have started to apply biotechnology and nanotechnology” (Hietanen 2012, p. 39). Learning from what has occurred in the past allows us to forecast what will happen in the future. If such major change, growing at an exponential pace, has occurred in the last decade, then it can be assumed that the world in terms of material use will be very different in 2030 to the world known today. Despite the many threats and challenges, humanity may still remain positive about the future as “the embryonic revolution now taking place... offers strong evidence that there are no limits to growth” (Tsvi 2012, p. 29).

4.1 Peak Oil

Everything produced requires oil at some part of its journey from a raw material to its final product when purchased by the consumer. The term ‘Peak Oil’ refers to the point in time when the extraction of oil is at a maximum, after which a steady and non-recoverable decline occurs. “The experience of two oil price shocks in the 1970’s and the more recent one in 2008 leave little doubt that oil is a resource which a decline could prove very costly” (Boyce 2013, p. 92). Oil is continually being discovered however, as shown in figure E1, and the question currently in debate is when will extraction reach its peak?

The main challenge to the material sector is the idea that an efficient, renewable replacement for oil be discovered and implemented for when oil inevitably runs out. Every industry will be negatively affected unless alternative means of production are found. With oil prices assumed to reach US$300/barrel, a combination of two occurrences will take place; the price of all materials will rise and a substitute will be created.
4.2 Climate Change

It has been argued that “Even the most aggressive global movements...can do little to avoid a significant shift in the global climate system” (Dave 2012, p. 2). As previously discussed in this report in section 2.1, climate change will play a significant role in determining how the landscape of the material sector will appear. Due to the steady current climate, a change of $\pm 2^\circ C$ should be anticipated as it is assumed in this report that over the next few thousand years, shown within figure B1, the earth will go into a glacial period. However, this will not take significant affect over the next few decades. “While there is debate around what level of adaptation is needed, there is growing awareness that design practices need to take into account predictions of increased risk and intensity of extreme events” (Snow 2011, p. 2). Figure E2 illustrates potential effects on the use of materials in the construction industry should climate change occur. In an attempt to reduce carbon emissions, as an example, wood seems a more viable option as opposed to steel or concrete which are highly carbon intensive materials. If the past few decades give an indication as to the variety of materials used, then not much change will occur in the future. However, with a sustainable outlook and the need to adapt to a changing climate, significant climatic events could be predicted which will be discussed further in this report.

4.3 Increasing Cost of Water

Australia already has an unreliable water situation when drought can take over at any time. Climate change and increased unpredictability of rainfall, have led to the assumption that the availability of irrigation water has been reduced to 20% of the yearly average allocation by 2030. This would also lead to the assumption that water resource levels are considerably low and innovations need to be advanced to provide water security for Australia. The impact this will have on the materials industry will be felt across all other industries. The price of water will rise significantly
therefore smarter practices of producing materials must be adopted. For example, “One important challenge in the coming years is to invent new ways of farming, able to produce more with less water” (Bossuete 2012, p.63). This example will be the same across all industries, being able to produce the material with an increased focus on water saving production.

4.4 Resource Depletion

“Energy consumption, depletion of natural resources and human induced natural disasters have all conspired to raise the profile of “sustainability”, particularly environmental sustainability” (Bernal 2012, p. 177). With the continual growth and development of the human race, as discussed in Appendix D, it is to be expected that more resources will be necessary in order to provide the level of comfort Australian society is accustomed to. This is heavily impacting on the environment with the over use of non-renewable resources whereby, unless recycled, will be completely gone in the future. As an example, Australia is a major exporter of coal which in turn, is discouraging the need for renewable energy sources for the importing nations. “The problem of the depletion of resources used in production remains critical, as can be seen in discussions of such issues as: declining freshwater resources, peak (crude) oil, loss of soil fertility, and shortages of crucial minerals like zinc, copper, and phosphorus” (Magdoff 2013, p. 13). As materials become scarcer, they will become more expensive to provide and purchase, making them uneconomical to consume. This idea presents the challenge that by 2030 non-renewable resources will need to be substituted by renewable ones, a topic which has been studied and trialled to date with little impact.

4.5 Infrastructure Replacement

The nature of current infrastructure is one that is built with a finite life. This puts the material sector in a good position in that it is ensured continual business in the future. However, if it continues to provide materials at the current pace, it will find it is
unsustainable and will have to raise prices or find substitutes. The challenge will be to find renewable substitutes for the infrastructure if recycling is not a possibility.
5.0 Current Trends, Future Directions and Solutions

If we continue on the same path without change, society will remain dependent on materials that consume resources which will lead to depletion. Current procedures and processes to develop these materials are highly energy inefficient. Globally humanity consumes $500 \times 10^9$ billion joules (EJ) with 86% of that consumption being sourced from fossil fuels (Ashby 2009). To predict future materials, it will be assumed that by 2030 the majority of electricity generation is still sourced from fossil fuels but is in a transition to renewable sources. In addition, the material life cycle change will be highly driven by population growth, energy sources, water availability, depleting land resources, climate change and national security (Ashby 2009).

5.1 The material life cycle

To establish future materials in 2030 it is important to understand material life cycles which include their raw materials and extraction of these materials, design processes and uses in the built environment (Jeganova 2004).

The material life cycle involves assessing the environmental impacts associated with the full life of products, from the extraction of raw materials to their return to the environment as waste (Kendall, Keoleian & Lepech 2008; Ashby 2009). To assess materials on embodied energy alone is not sufficient in evaluating their environmental performance as many materials can be used and modified after their initial use (Kendall, Keoleian & Lepech 2008; Treloar, Love & Faniran 2001).

5.1.1 Embodied Energy

The embodied energy of materials is the sum of all the processes associated with the fabrication of a product which can include energy from manufacturing, design, transport, maintenance and disposal (Treloar, Love & Faniran 2001).
5.1.2 Resource Extraction – Raw Materials
Energy and materials that are consumed at this point deplete natural resources (Ashby 2009). Consumption brings an associated penalty of carbon and as their concentrations build, they become damaging to the environment (Ashby 2009; Jeganova 2004). The study of resource consumption, emissions, and their impacts is called a life-cycle assessment (LCA) (Kendall, Keoleian & Lepech 2008).

In Australia, raw materials such as iron ore, nickel, coal and uranium are abundant and are responsible for the wealth of the Australian economy. It is expected that by 2030 further mineral reserves will be found throughout Australia and the world.

5.1.3 Current Design Process
The design process of materials refers to the development of the end product through manufacturing processes. This process is integral in guiding environmental enhancement of product systems through system analysis, identifying and evaluating the environmental performance, cost, cultural and legal requirements as well as stakeholder participation (Jeganova 2004). The design process requires input from engineers, product managers, sales members, distributors, consumers and suppliers (Jeganova 2004).

5.1.4 Waste Management
At the end of a product’s useful life they are discarded and a fraction of the materials they contain perhaps entering a recycling loop, the rest committed to incineration or landfill which contributes to the overall embodied energy of the material (see section 5.5 Recycling) (Ashby 2009; Jeganova 2004).
5.2 Sustainable Technology

In the future (2030), technology will play a large role in improving efficient and economical extraction and design processes in all materials. Technological advances at the operational stage are driven by better ways to run business operations with lower environmental impacts and resource consumption and higher profitability (Van Berkel 2006). Such advances include:

*Operations and Maintenance*: better operation and maintenance procedures and practices to improve process efficiency through chemical developments to enhance the recovery of minerals and minimise the creation of waste and emissions (Van Berkel 2006).

*Process Inputs*: better control of incoming materials (from extraction) to minimise the input of impurities into the process and use more efficient, less toxic and/or renewable process inputs (Van Berkel 2006).

*Reuse, Recycling and Recovery*: additional uses of reuse, recycling and recovery processes and loops to recover materials, water, heat and/or other valuable materials (Van Berkel 2006).
5.3 Steel & Concrete in the Future

Two major materials used in the world are steel and concrete, as they provide the built environment with robust end products. Both materials however, use large amounts of CO₂ in their production and therefore have high embodied energies. Technology and research will allow for chemical and design changes to be made to make these materials increasingly sustainable in 2030.

5.3.1 Steel

Steel is a major component for a wide range of market applications and products, such as in the automotive, construction and packaging sectors (World Steel Association 2013).

Steel manufacture includes extracting iron ore, smelting the iron from its ore, adding other metals to it and casting it to form mainly structural elements (World Steel Association 2013). This process is highly energy inefficient and approximately 70% of the world’s steel is made by the blast furnace process which is highly carbon dependant (World Steel Association 2013). Steel’s embodied energy is relatively high (21 MJ/kg) when compared to other construction materials making its overall material life cycle quite energy intensive (Greenspec 2013).

Ongoing research and technology continue to develop new steels that are even stronger than their predecessors, and thus will minimise the mass of future steels in 2030 (World Steel Association 2013). Within the last 10 years steel weight has declined by approximately 50% whilst still maintaining its strength properties and has saved more than 200 T of CO₂ (World Steel Association 2013).

Furthermore, steel is necessary for both the production and supply of energy whether it be for future renewable energy or the continuation of fossil fuel use. It is used in electricity pylons, offshore oil platforms, hydroelectric power stations and wind facilities (World Steel Association 2013). Without steel, the infrastructure to supply electricity to our homes would be extremely inefficient.
In 2030, steel will still be the material choice for construction and manufacturing around the world as it is one of the most efficient modern construction materials. It offers the highest strength-to-weight ratio of any commonly-used material and is exceptionally durable (World Steel Association 2013). Additionally, it will be able to be designed for the purpose of the end-use, specific strength, durability and end-of-life recycling requirements. New manufacturing processes have also introduced environmentally-responsible production methods (See Section 5.5).

5.3.2 Concrete
Humans have been using concrete in the built environment for millennia as it allows for flexibility in the design process to achieve versatile end products. The basic ingredients; aggregate, a cement-like binder and water were being mixed as far back as Egyptian times (Crow 2008). In the nineteenth century, Portland cement (main ingredient in concrete) was discovered and created the modern concrete we see today (Crow 2008).

Concrete is used so widely that world cement production now contributes 5 per cent of annual global CO₂ emission production and it is even said that for every tonne of cement made a tonne of CO₂ is produced (Kendall, Keoleian & Lepech 2008). This large production of CO₂ is mainly due to the manufacture of Portland cement as it requires significant amounts of energy to reach reaction temperatures (Crow 2008). Although, if you replace concrete with any other current material, it would have a bigger carbon footprint, such as replacing it with steel, as the embodied energy for concrete is only 1.3 MJ/kg compared to 32 MJ/kg for steel (Crow 2008).

Current technology has allowed for cement kilns to produce 200 kg less of CO₂ per tonne which should decrease in the future allowing concrete to be continually used in 2030. Ultra strong varieties of concrete can be achieved by adding admixtures to the mix such as plasticisers (Crow 2008). Further technology and research into efficient chemical admixtures will decrease the embodied energy of concrete whilst increasing the strength. Another way to combat the high CO₂ emissions is to replace the use of Portland cement through the use of waste materials such as fly ash (from coal fired power plants) and slag (from blast furnaces) (Crow 2008). This recycling of
waste material is highly energy efficient and allows for steel manufacturers and coal fired power plants another avenue for waste disposal.

In 2030, concrete will be continually used due to its flexibility in design, high viscosity and high strength as well as it's continual CO$_2$ reduction through advances in technology.

5.4 Recycling

Recycling products is a way in which new products can be produced with a lower overall embodied energy and therefore reducing CO$_2$ emissions. Such recyclable materials include steel, concrete and wood.

Of all the construction materials steel is the most recycled with 82% of Australian scrap and waste steel being recycled into prime new steel products (World Steel Association 2013). As mentioned 70% of steel is produced using the blast furnace method, with the other 30% made by recycling scrap which is not dependant on carbon rather, dependent on the availability of scrap (World Steel Association 2013). Utilising recycled steel reduces the embodied energy to 8.8 MJ/kg which is a staggering variation.

Concrete recycling is increasingly common as the rubble can be transformed into aggregate through crushing the concrete (Lindsell & Mulheron 2007). By utilising this method it reduces construction costs (lower costs than quarried products), reduces the CO$_2$ emissions when compared to transporting aggregate from quarries, keeps concrete debris out of landfill and reduces water consumption (Lindsell & Mulheron 2007; Crow 2008).

Wood recycling is a viable recycled material as it can be utilised aesthetically, structurally and reduced down to form part of engineered wood products such as particleboard and fibreboards (Timber Development Association 2013). Although a large hindrance to this process is the increase in costs in demolition as time is used to preserve the wood’s integrity. As wood products continue to be used in 2030, the
recycling of wood will enable this use to be environmentally friendly and limit deforestation.

On large scales, recycling is a viable source in the future in reducing CO₂ emissions with the help of future research, technology and availability of recyclable materials.

### 5.5 Other Materials

As well as addressing the major materials such as steel and concrete, this section will demonstrate the impact of other materials growing in popularity. These materials will have a significant effect on the industry in the future and will be continually developed to make them competitive in production.

#### 5.5.1 Ceramics & Glass

Ceramics are inorganic, non-metallic materials, created from either soil or chemically processed powders. Typically ceramics are produced by compounding metallic and non-metallic elements together, such as aluminium oxide. Glass is an amorphous subset of ceramics and is most commonly used for windows in infrastructure.

Ceramics are currently, by far, the most used material in the world as can be seen from figure 1. This dominance of usage is due to concrete being so widely used. Concrete is employed in the majority of infrastructural applications because of its current idealistic structural properties. Cement is the specific part of concrete that is classed as ceramic.

The production of cement is a very energy intensive process. Presently, there is already much investigation into alternatives to the commonly used, Portland Cement, in concrete. The alternatives must be competitive in structural strength applications and be readily available. Many potential cost effective alternatives already exist such as; fly ash, burnt clay or casein, as well as polymers.

By 2030 it can be expected that a suitable alternative to Portland cement exerting similar, if not more desirable, properties will be in place. This alternative most likely
lies with that of polymers when their cost efficiency has been increased. In relation to glass, 'green' plastics will be the best option in the future. Perspex like materials mimic characteristics of a glass window whilst being a better insulator, cheaper on the environment to produce and simple to recycle will exist.

5.5.2 Biomaterials
Biomaterials are synthetic and natural materials that interact with biological systems (UWEB, 2004). These materials combine ideas from medicine, biology, chemistry, material science and engineering. Biomaterials can be metals, ceramics, polymers, glasses, carbons, and composite materials. These are used as moulded or machined parts, coatings, fibres, films, foams and fabrics (UWEB, 2004).

Current applications of biomaterials are predominately used in medicinal cases. They are also used to; grow cells, systems of blood proteins, used in biotechnology, in fertility regulation, diagnostic gene systems and investigational cell-silicon ‘biochips’ (UWEB, 2004).

Biomaterials technologies aim to address cost, minimisation and infection prevention, the three key pillars of current healthcare (MDDI, 2011). The focus into the future is to use biomaterials to regenerate tissue in medical cases, instead of replacement.

Currently the applications of biomaterials in infrastructure are minimal, however, for future prospects their uses are numerous. In essence, biomaterials can potentially replace all plastics (Sustainable Biomaterials 2013). The main difficulty is creating a material that meets current standards whilst maintaining sustainability requirements; as is the case with many sustainable materials. 2030 will look to see biomaterials as a major plastic substitute, especially for non-structural applications.

5.5.3 Natural Materials
Natural resources are materials that occur naturally within the environment. Every manmade product is composed of natural resources at its fundamental level (Boundless, 2013). Natural resources may need to be processed to obtain the
resources for use in infrastructure, for example; metal ores, oil and most forms of energy (Boundless, 2013). Sunlight and air are known as ubiquitous resources, as they can be found everywhere. The alternative, found in specific locations are known as localised resources. There are also many natural resources that serve as energy sources, from coal through to wind, there is a vast range of options for power generation.

Natural resources such as water and soil/rocks can be recycled, modelled, developed and applied to infrastructural design and engineering. For example water is used in sewer and drainage, cleaning, consumption and electricity generation; soil/rocks are used primarily for foundations, as well as embankments, road bases, rail ballast and concrete aggregate. These materials serve their purpose very effectively and efficiently. Some of their uses cannot even be substituted by other materials. This said, it is likely that they will continue to be used very similarly throughout this century. Conversely, there are many other natural materials whose usage will change over the coming years.

There is widespread debate over the potential overuse of natural resources; the exportation of natural resources is the basis for many economies across the world (Boundless, 2013). All infrastructural development stems from the core commonality of the use of oil, a valuable exhaustible natural resource. Other natural resources such as water and air are used in energy producing applications such as hydro and wind technology. While wind farms and hydro technology is fast advancing the prime producer of energy remains coal-fuelled power plants.

Renewable, natural resources are those that need to be exploited over the coming decades. Continual heavy investment needs to applied to research in these renewable materials. With enough advancement the possibility of a perpetual, society sustaining, energy source may come into fruition. This outcome is idealistic, however the more that these renewable, natural resources are employed in sustainable ways, the closer that this will become a reality.
5.5.4 Geofabrics

Geofabrics are a synthetic material; a woven or nonwoven fabric consisting only of continuous chain polymeric filaments or yarns of polyester or polypropylene (James, 2012). They are a very effective and efficient material. They serve as a means of saving money, saving space as well as prevention of damage and loss of other materials.

Geosynthetic products are used in road and railway construction, mining and resources projects, landfill and coastal engineering applications (Geofabrics, 2013). A common geofabric - Tensar - is used to reinforce slopes beside road or highway construction. Geofabrics also aid in prevention of soil and liquid loss and stabilisation of soft pavements or soils. Elcoseal is another geofabric product used as a geosynthetic clay liner. This product is also used in landfills as base lining, water containments and storm water detention systems, mining closures, and fuel storage tanks (Morrison, 2013).

Geofabrics are required for many projects currently and their necessity will only increase with time. In 2030, geofabrics will not only be standard for developments but required by law. They will also be used more heavily in conjunction with other innovative materials such as nanotechnology to improve them.

5.5.5 Polymers

Polymers consist of long chains of monomers, a monomer is a specific molecule which is repeated to form the chain (Hall 1981). Polymers occur naturally, such as wool or natural rubber; they can also be synthesised and are used mostly to create plastic products (Minnesota University 2012).

Polymers can emulate many of the uses that biomaterials presently carry out and will fulfill. The major difference is polymers are not comparatively biodegradable to biomaterials. This said, they are still much better than typical plastics and given their nature, can always be improved.

It is likely that polymers will serve roles in construction and fill the voids that biomaterials cannot for the plastics industry. There is a large amount of scope as to what polymers can be used for due to them being synthesised. They are already
used as surface materials and decal in construction. By 2030, there will be structural uses for polymers, particularly relating to replacement as cement in concrete; the possibility of polymer structural members also exists.

**5.5.6 Nanotechnology**

Nanotechnology is currently on the forefront of ‘futuristic’ and innovative technologies and materials. It deals with matter at the atomic and molecular scale. As a material the extent to which it can be used is almost boundless, it can be used almost anywhere (Hristozov 2009). This is due to their ‘customisability’ and design of end products/materials is only limited by human ingenuity.

Nanomaterials aren’t currently in considerable use globally, however the next decades will see a large influx of applications and uses for nanotechnology. These materials particularly hold promise for energy production and pollution mitigation. This is due to findings where nanotechnology promotes optimisation in sensing, detection, and treatment for the environment; as well as monitoring, treatment and remediation for pollution (Hristozov 2009).

**5.6 Future innovations**

Technological advances and further research into material behaviour and science will allow for advancements in materials in 2030 that will permit them to be used in a wider variety of applications. A number of innovations of steel and concrete have already been mentioned although, there are potential materials that will be on the market in 2030 that can further enhance the sustainability of infrastructure.

**5.6.1 Primary Innovations**

*Adobe:* a variation from the general adobe that consist of straw, earth and compressed by mechanical means therefore eliminating the CO$_2$ emissions from the generation on cement will be a useful composite of materials in the future (Revuelta-Acosta, Garcia-Diaz, Soto-Zarazua & Rico-Garcia 2010). Adobe and earthen
materials can be utilised in house construction where it is found that approximately 370 GJ of energy can be saved per year using this construction material as well as the reduction of CO$_2$ by 101 tonnes per year (Revuelta- Acosta et al 2010). Additionally, fibre reinforced mud brick houses have been found to be superior to concrete brick houses in reducing large fluctuations of indoor temperatures during the summer and winter periods (Revuelta- Acosta et al 2010).

One of the main advantages of adobe is that the raw materials are locally available and can even be produced from the soil excavated from the building site reducing transportation and other energy intensive processes.

**Nanocrystalline cellulose (NCC):** is produced by processing pure wood (lignin and hemicelluloses removed) which is then milled to a pulp, acid is then added which allows the mixture to crystallise into a transparent paste (Ferguson 2012). The paste forms a laminate type product which is dense, flexible, has a strength to weight ratio higher than stainless steel. When freeze dried the material is lightweight, absorbent and a good insulator (Ferguson 2012). The wood needed to make this material does not necessarily need to be trees, but can be branches, twigs and recycled (Ferguson 2012). Therefore, this material could be easily obtainable, cheap and utilising waste all at once.

In the future NCC could replace metal and plastic car parts, be used structurally in buildings and could make non-organic plastics obsolete (Ferguson 2012).

**Kinetic Glass:** is a transparent glass that automatically opens and closes gill-like slits in response to human presence to control the air quality in the room (Leontiou 2011). The surface is embedded with wires that contract due to electrical stimulus which
allows the gills to regulate air quality by breathing the air (Leontiou 2011). This material allows for quality air to be provided in buildings and homes whilst monitoring CO₂ levels outside.

**Self-Repairing Cement (materials):** this variety of cement is mixed with microcapsules that release a glue-like epoxy resin that automatically repairs any cracks that form in the sidewalk or roadway (Leontiou 2011). Additionally, this cement will have the ability to regulate heat due to the added phase change materials also added to the mixture (Leontiou 2011).

This technology is not only being used in cement but in all materials such as metals and plastics where any damage is self repaired which would make their useful life somewhat infinite. With these materials we would cut all repair work, costs and CO₂ emissions from infrastructure maintenance.

**Liquid Granite:** is made of 30-70% recycled materials and uses less than a third of the cement use in concrete. This means that it has a much lower embodied energy and CO₂ production (Leontiou 2011). Liquid granite has the ability to replace cement in concrete as it has the same load bearing capacity of cement, but has increased eco-friendly properties.

Finally, liquid granite is fire resistant and can withstand temperatures of up to 1,100°C while still maintaining its structural properties (Leontiou 2011). This property of the material is highly advantageous in developing sustainable infrastructure in the future.

**Bendable Concrete:** concrete alone is brittle and weak under tension, any buckling or bending will cause it to crack which is why steel is used for reinforcement.
Although, a new variety of concrete currently under investigation is around 500 times more resistant to cracking than regular concrete (Leontiou 2011). This concrete is made up of tiny fibres that slide within the concrete allowing it to bend with the help of other materials within the concrete (Leontiou 2011). This material could increase the versatility of concrete that otherwise would of been over looked by eliminating some steel reinforcement and therefore, saving costs and reducing overall CO₂ emissions.

5.6.2 Secondary Innovations

*D3O*: is a unique polymer composite, containing a chemically engineered dilatant capable of functioning as an energy absorber. It has the potential for application where impact protection is vital and is currently believed to lead the innovation of smart fabrics within this area.

*LiTraCon*: is a trademark for a translucent concrete building material currently being trialed for small applications. Technically speaking the concrete consists of 4% by weight of optical fibres with the remainder coming from the concrete. Given the recent success of LiTraCon projects, it may produce an efficient alternative as it is stronger than glass, despite its translucent appeal.

*Graphene*: is simply an atomically thin layer of mineral graphite packed into a two-dimensional honeycomb lattice with superlative properties. It is considerably light (1m² weighing only 0.77mg) and has potential to be utilized as a basic building block for graphitic materials. For instance it can be wrapped up into 0D fullerenes, rolled into 1D nanotubes or stacked into 3D graphite.

*Solar shingles*: or photovoltaic shingles as they are technically referred to, are solar cells
designed to look like current asphalt shingles. They provide the benefits of solar energy recovery whilst minimizing the negative aesthetic effect currently seen from solar panels. Some companies in America and Europe have begun to manufacture solar shingles however only on a small scale.

_Aerogel_: is described as having the lowest density than any other solid state material on earth. It provides a potential substitute for low-density structural materials and exhibits the lowest conductivity of any solid known.

![Aerogel](image)

Amorphous _metals_: are solid metallic materials that possess a glass like structure. Unlike glass they have good electrical conductivity. Its elastic modulus is consistent to that of bones, it has a high ‘wear’ resistance and does not undergo shrinkage on solidification. These properties make it an excellent substitute in smaller applications within infrastructural development.

_Metal foam_: is simply a cellular structure of a solid metal containing a large volume percentage of gas-filled pores. It exhibits a very high porosity and thus is considered an ultra-light material. Current investigations suggest that it may have a successful application within the automotive industry as a substitute for current construction materials. Given its light weight and strength, it is believed to have significant applications in the future.
*Bio algae plastic*: Current investigations into bio algae plastic have suggested that there is a potential to consider it as a sustainable material. However scientists are still addressing the challenges associated with quality, and affordability. By 2030 the use of bio algae plastic in ropes will be a high possibility.
6.0 Organisational Adaptation to Industry Shifts

With large changes to the material industry to be expected by 2030, organisations must be aware of the need of flexibility required to ensure future success. For maintained competitive advantage, adaptability is crucial. As the material industry is shifting towards sustainable production to align with other major industries, significant planning will need to take place to support business needs with consumer and legislative needs.

6.1 Consumer Satisfaction in 2030

Consumer needs will change by 2030, just as they have done in the past 20 years. The amount they change will rely upon influences discussed in section 7 of this report. Consumers may shift from a highly capitalist society to one of permaculture and sustainable living. Alternatively, they may continue on a path of high consumption and production where advancements in technology will aid a consumerist society. For either case, or anywhere in between, organisations will need to provide alternative products to deal with consumer changes and demands. In order to meet customer demands, global trends will need to be monitored in order to fully provide information to satisfy customer requirements in the future.

6.2 Strategic Planning for Cost Efficiency

When planning for the long term future, organisations within the material industry will need to understand and be able to utilise new technologies as they are implemented. They will need to be employed sustainably but effectively and adapted to fit the company’s needs for efficient output.
Organisations will also need to be aware of new innovative ways of production and will need to adapt to inventive solutions by competitors. There may also be a future market for sustainable goods as opposed to those made from non-renewable products. Successful planning will occur through innovation and a change of thought to sustainable production within the material industry.

6.3 Legislative Compliance

As we are currently seeing with the carbon tax, there is a large political impact on material production. The effects of climate change will dictate whether some materials will be heavily taxed or outlawed all together. As the effects of producing some materials are discovered, a change in legislation may occur which completely stops production of some materials, just like in the past with fluorocarbons and asbestos. In 2030 it can be expected that sustainability will be a key factor in political decision making and will affect the outcome of political races. Therefore, the material industry can expect politics to impact on their production and prepare accordingly.

6.4 Technology

Developments in technology will be the key to a sustainable future. Previous technological advances have created a highly efficient materials sector which can be predicted to continue in the future. It will allow for composite materials to be created with sustainable properties as well as enhanced material properties.
7.0 Influences

The material sector is influenced significantly through many different factors as detailed below. It is expected that the industry will be influenced greater by external factors by 2030 than what it is today.

7.1 Building and construction sector

The building and construction sector has had a great influence on the material sector, one which will continue well into the future. The building and construction sector is responsible for a major proportion of the consumption of materials and thus controls the supply and therefore, production rate of many materials.

7.2 Energy sector

The energy sector will have an overriding impact on the materials sector in the near future. The pursuit to develop environmentally friendly energy sources and efficient practices is becoming more urgent as time progresses. Whilst small changes are always evident within the energy sector, we face the task of transitioning from predominantly non-renewable sources to renewable sources in the near future. This has the potential to greatly influence the processes we currently use to produce materials and also the types of material that we consume.

7.3 Economy
The Economy has a significant influence on the material sector with changes occurring on a daily basis. The use of commodity prices to control and balance the supply and demand of raw materials is essentially what can decrease production and allow for profitable resource collection. Such a heavy reliance on the economy makes the material sector extremely vulnerable should a significant event take place, for example, the 2008 crash.

7.4 Government

The Government, having the ability to control the economy, can also greatly influence the materials sector. Whilst the majority of the materials sector within Australia and the globe is controlled by the private sector, the government is able to introduce policies which essentially control the actions of these large companies. Within Australia and other developed countries over recent years there have been debates on whether or not the implementation of a carbon tax should be integrated into the system, and also if these emissions even have any significant effect on our environment.

7.5 Global relations

Strong global relations are essential for any global problem throughout the world. They control the import and export of materials for countries which would otherwise have too much or too little of a material. This has allowed nations to develop beyond their individual capacity and expand to the magnitude that is evident today.

With majority of the materials sector being import and export, a shift in global relations has the potential to have a significant influence within the materials sector, both here in Australia and globally. Currently Australia has a large trade with China and India, emerging global superpowers. Should these export and import relationships with these countries be threatened in the future, Australia’s export demands could decrease presenting issues to the economy.
Conflicts such as those experienced in the Middle East could also present problems for the materials sector. Oil production out of these areas could be slowed and drastically affect prices in Australia.

An increasing focus in ‘green’ technology creates a lower demand for materials such as steel and coal in Australia’s export industry. This will create a job shortage and decrease in money received to Australia, whose main source of income is from material export.

7.6 Environmental Considerations

As this report is focussed on a sustainable future, environmental considerations will greatly influence the future of the materials sector. Greenhouse emissions, along with the need to produce materials efficiently in an environmentally friendly manner will be emphasised in the future.
8.0 Conclusion

This report was designed to allow organisations within the materials industry to understand the challenges it will be faced with in the near future. It aimed to equip them with enough information to help decision making on how to adapt to sustainable production.

Sustainable manufacture is increasing in popularity on a global scale and Australia needs to adapt to survive in the changing material sector landscape. As Australia relies heavily on material production as its primary source of income, maintaining its advantage will require significant change as technologies in the industry increase.

There are many factors that will affect the material sector significantly. These include; population growth, climate change, peak oil, resource depletion, legislation, technological advances, the energy sector, the economy (both global and local), international relations and environmental concern. Each of these factors have the potential to completely change the industry and when combined, will pose great challenges.

Significant advancements in materials currently used have occurred in the last few years and expectations that they could be further advanced is reasonable. Reliance on these materials alone creates sustainability issues and in the future, must be used in combination with innovative materials discussed within.

Sustainability within the material sector is based on the use of renewable resources, recycling and reducing the overall embodied energy of the material. As Australia moves toward a sustainable future, these ideas will be the key to efficient and eco-conscious living.

It is advised for organisations within the material sector to prepare to introduce sustainable concepts into design and production of their material. By 2030, there will have been much advancement in the materials currently used, as well as completely new materials being produced. If competitive advantage is to be maintained,
organisations will need to adapt and develop in combination with global trends toward a more sustainable future.
Appendices
Appendix A – References


Boyce, J 2013, “Prediction and Inference in the Hubbert - Deffeyes Peak Oil Model”, *The Energy Journal*, vol. 34, no. 2, pp. 91-142.


Appendix B – Climate Analysis

The following appendix consists of evidence necessary to demonstrate that climate change is inevitable. It looks into historical records over various scales along with the parameters believed to greatly influence our climate.

The first three figures look into temperature variance of the globe over different scales and talk about the trends compared to CO₂ emissions. They conclude that current temperature variations by the earth are not unique to what has been experienced in the past, and that CO₂ effects are minimal or absent when considering average global temperature change.

![Figure B1. Geological Scale of climate change](http://www.climate4you.com/GlobalTemperatures.htmSource)

Figure B1 shows the last four glacial (troughs) and five interglacial (peaks) periods experienced within the last 420,000 years on a geological scale. From the graph it is evident that the interglacial period which is currently experienced has a temperature much less than the other four, 1-3°C. It is also alarming that the interglacial periods
last typically between 10,000 and 15,000 years, with the current interglacial period being 11,600 years in. This data was based on studies analysing the Vostok ice core from Antarctica. Modern temperature is indicated by the horizontal dashed line. The red rectangle to the right is considered to be modern time and is further represented in figure B2.

Figure B2. Comparison of air temperature and CO₂ for Greenland.

Source: Climate4you, http://www.climate4you.com/GlobalTemperatures.htmSource , 28/05/2013

Figure B2 shows two graphs, the first being the air temperature over the last 10,700 years and the second the levels of atmospheric CO₂ within the same time period for Greenland. The purpose of comparing these two graphs is to show that the increase in CO₂ has little direct impact on temperature change. A decreasing temperature
trend is evident over the last 3,000 years with the graph showing significant warmer periods (peaks). The presented data was again derived from analysing ice cores in Greenland.

Figure B3. Recent satellite data showing variations in temperature.

Source: Climate4you, http://www.climate4you.com/GlobalTemperatures.htmSource, 28/05/2013

Figure B3 looks at much more recent time, i.e. since 1850 where global temperature variations can be accurately estimated from meteorological observations. The slight temperature increase is believed to be in response to the little ice age more clearly shown in figure B2 (see 500 years from now).
Figure B4. Various methods of recent temperature data collection

Source: Climate4you, http://www.climate4you.com/GlobalTemperatures.htmSource, 28/05/2013

Figure B4 shows again much more recent temperature data between 1979 and projected to 2013 for the organisations and varying data sources since satellite observation has become available. Below is a list of what the acronyms stand for.

- University of Alabama in Huntsville, Microwave Sounding Units (UAH MSU)
- Remote Sensing Systems, Microwave Sounding Units (RSS MSU)
- Goddard Institute for Space Studies (GISS).
- National Climatic Data Centre (NCDC).
- Hadley Centre for Climate Prediction and Research and the University of East Anglia’s Climatic Research Unit (HadCRUT4).

Upon comparing the data it can be seen that majority lie within a similar trend; a few outliers are evident however only fluctuate 0.2°C at most. This figure therefore helps us gain a better appreciation of the data and assists in its credibility.
Appendix C – Global Material Analysis
The following appendix presents the evidence necessary to convince the reader of the rising trends in material production. It looks at recent World statistics and then Australia’s influence for various raw materials used throughout infrastructure development. It concludes with the effects that the material sector has on the environment, considering the current statistics.

Figure C1 presents the world demand in metric tonnes of four predominant materials used over the last half century. Figure C2 looks more closely into the important metallic materials, again presenting the world demand in metric tonnes. Both figures show a significant increase which is further evident in recent years. The data presented was taken from the U.S. Geological survey (2013) and has since been summarised and represented for clarity.

Table C1 further highlights this rapid growth within the material sector by presenting the current annual growth rates of selected materials. An analysis below the table is then compared to the global population growth.

Production for a few predominant Australian materials is compared with the rest of the world in Table C2 for both 2000 and 2010, as recorded from the resource and energy statistics, 2011. This again shows an increase in production and provides the reader with an understanding into the magnitudes of the predominant materials at both national and global level.
Figure C1. Global raw material demand.


Figure C1 shows a graphical representation of the World demand for the most predominant raw materials. From the graph it is evident that cement and raw steel have rapidly increased over the last 10 years, with cement being the material in most demand. Industrial and fuel wood remains relatively constant with small fluctuations. This is to be expected when considering that the economic growth is much more rapid than the population growth, thus per capita goods of all kinds is rising globally. Other raw materials such as limestone, clay, sand and gravel are consumed in much greater demand than those above. This data was excluded in order to accurately present the information.
Figure C2. Shows the predominant raw minerals consumed globally.


Figure C2 Shows a graphical representation of the World demand that was met for ‘important metals’, used extensively throughout various infrastructure developments. When compared to figure 1, the magnitude in figure 2 is significantly less, being simply a result of abundance and therefore availability of the material. Since the data has been obtained in the 1960s, a steady increasing trend has been evident for aluminium, copper and zinc and nickel. Lead and Tin (which is of a very small magnitude) remain rather constant.

<table>
<thead>
<tr>
<th>Material</th>
<th>Rate (X…)</th>
<th>Steel</th>
<th>Cement</th>
<th>Aluminium</th>
<th>Plastics</th>
<th>Wood</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4.26</td>
<td>11.10</td>
<td>9.45</td>
<td>48.33</td>
<td>1.68</td>
<td></td>
</tr>
</tbody>
</table>

Table C1. Principle raw material annual growth rates, global

Source: Data for wood from FAO (2013); for cement, steel, and aluminum from the U.S. Geological Survey (2013); and for plastics from the Association of Plastics Manufacturers in Europe (2013).
Table C1 above shows the alarming increase to the annual rate of material generation for various primary materials globally. When compared with a global population growth rate of approximately 2.28% it is clear that our global demand for materials is increasing at a greater rate.

<table>
<thead>
<tr>
<th>Material</th>
<th>Production 2000</th>
<th>Production 2010</th>
</tr>
</thead>
<tbody>
<tr>
<td>World</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aluminium (kt)</td>
<td>32807</td>
<td>45094</td>
</tr>
<tr>
<td>Black coal (Mt)</td>
<td>32807</td>
<td>6020.2</td>
</tr>
<tr>
<td>Iron ore and steel (Mt)</td>
<td>1159.7</td>
<td>1814.7</td>
</tr>
<tr>
<td>Australia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aluminium (kt)</td>
<td>1769</td>
<td>1928</td>
</tr>
<tr>
<td>Black coal (Mt)</td>
<td>321.48</td>
<td>471.09</td>
</tr>
<tr>
<td>Iron ore and steel (Mt)</td>
<td>213</td>
<td>419.9</td>
</tr>
</tbody>
</table>

Table C2. Production comparison for some predominant raw materials used in infrastructure development


Table C2 shows the magnitude and change between 2000-2010 for the production of some raw materials for both Australia and the World. From the table it is evident that production has significantly increased. Formal data, revealing more recent production rates is scarce, however it is found to be increasing.

Within the materials sector the above was presented simply for comparison on a global scale. When looking more into infrastructural development the more predominant materials are presented in figure C3. These materials are categorised into metals, polymers, ceramics and hybrids and are presented showing their
embodied energy (figure C4), usage (figure C5) and annual world production (figure C6).

<table>
<thead>
<tr>
<th>Metals and alloys</th>
<th>Polymers and elastomers</th>
<th>Ceramics and glasses</th>
<th>Hybrids: composites, foams, and natural materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum alloys</td>
<td>ABS</td>
<td>Brick</td>
<td>CFRP</td>
</tr>
<tr>
<td>Magnesium alloys</td>
<td>Polyamide PA</td>
<td>Stone</td>
<td>GFRP</td>
</tr>
<tr>
<td>Titanium alloys</td>
<td>Polypropylene, PP</td>
<td>Concrete</td>
<td>Sheet molding compound</td>
</tr>
<tr>
<td>Copper alloys</td>
<td>Polyethylene, PE</td>
<td>Alumina</td>
<td>Bulk molding compound</td>
</tr>
<tr>
<td>Lead alloys</td>
<td>Polycarbonate, PC</td>
<td>Soda-lime glass</td>
<td>Rigid polymer foam</td>
</tr>
<tr>
<td>Zinc alloys</td>
<td>PET</td>
<td>Borosilicate glass</td>
<td>Flexible polymer foam</td>
</tr>
<tr>
<td>Nickel-chrome alloys</td>
<td>PVC</td>
<td></td>
<td>Paper and cardboard</td>
</tr>
<tr>
<td>Nickel-based superalloys</td>
<td>Polystyrene, PS</td>
<td></td>
<td>Plywood</td>
</tr>
<tr>
<td>Low carbon steel</td>
<td>Polylactide, PLA</td>
<td></td>
<td>Softwood, along grain</td>
</tr>
<tr>
<td>Low alloy steel</td>
<td>PHB</td>
<td></td>
<td>Softwood, across grain</td>
</tr>
<tr>
<td>Stainless steel</td>
<td>Epoxy</td>
<td></td>
<td>Hardwood, along grain</td>
</tr>
<tr>
<td>Cast iron</td>
<td>Polyester</td>
<td></td>
<td>Hardwood, across grain</td>
</tr>
<tr>
<td></td>
<td>Phenolic</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Natural rubber, NR</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Butyl rubber, BR</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>EVA</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Polychloroprene, CR</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: 2013, Ashby, p460

Figure C3. Categorized materials used in infrastructural development.
A very important property of a material and one which often determines its environmental influence is embodied energy. Embodied energy is the sum of all energy required to produce the material from the raw stage right up until the end of production. Figure C4 above shows the embodied energy of various materials per unit mass, from the figure it is evident that metals and polymers show larger embodied energy compared with some ceramics and hybrids. It should be noted that this is a comparison of equal weight and has no reference to volume.

Embodied energy allows us to determine the efficiency of a material and the harm that it may play on the environment. Given our current procedures for material generation, potentially harmful emissions are being released into the atmosphere. As a result there is a requirement to lower these emissions by selecting or reducing the amount of embodied energy within a material.

This has somewhat shaped our current material usage as shown below in Figure C5 where the global usage of ceramics dominates any other category. This presents a real problem when considering the magnitude of production which is further
highlighted in Figure C6 below. Considering these figure it is evident that our demand for materials has become excessive and is greatly jeopardizing our sustainability. From here we have two options, either we significantly reduce our demand and thus production rates or we switch to alternative sustainable materials.

![Graphical representation of global production, by mass for various infrastructural materials.]

Source: 2013, Ashby, p19

Figure C6 shows a graphical representation of global production, by mass for various infrastructural materials.
As mentioned throughout the analysis it is clear that our current demand for materials is not sustainable. The current rate of production cannot simply continue with the expectation that everything will be alright. The need to adopt more sustainable materials is essential and the sense of urgency in which this should be done is paramount. Not only are non-renewable resources being depleted, but harmful greenhouse gases are being emitted into the atmosphere. This carbon footprint is believed to be contributing to our climate variation however no undeniable evidence has been produced.
Appendix D – Trends in Population

The population growth for both Australia and the World are presented below from 1966 to 2010. This data is shown in Figures D1 and D2 where the trends are identified.

<table>
<thead>
<tr>
<th>Year</th>
<th>Australia</th>
<th>Population (million)</th>
<th>World</th>
<th>Population (million)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1966</td>
<td>11.8</td>
<td>3400.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1967</td>
<td>12</td>
<td>3472</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1968</td>
<td>12.3</td>
<td>3545.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1969</td>
<td>12.5</td>
<td>3620.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1970</td>
<td>12.7</td>
<td>3696.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1971</td>
<td>12.9</td>
<td>3772</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1972</td>
<td>13.1</td>
<td>3848.3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1973</td>
<td>13.3</td>
<td>3924.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1974</td>
<td>13.4</td>
<td>4000.8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1975</td>
<td>13.6</td>
<td>4076.4</td>
<td></td>
<td></td>
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Table D1: Recorded population tabulated data


Figure D1. Population growth in Australia since 1966 – present.


Figure D1 shows the increasing population growth for Australia since 1966. Considering the trend we can expect a population of at least 27 million by the year 2030.
Figure D2. World population growth between 1966 – present.


Figure D2 shows the increasing population growth of the globe, with data taken from the Australian Government Bureau of resources and energy economics. Considering this trend we can expect a population of at least 8.6 billion by 2030.
Figure E1. Time Paths of World Crude oil production, discoveries and proved reserves, 1990 – 2010 (Boyce 2013, p. 98).

This figure clearly demonstrates that world production is far less than what is held in reserves and significantly less than the discoveries.
Innovative materials will need to be created in order to sustainably cope with changing climate in the future. Whether it is to increase insulation properties, withstand greater forces and temperatures or have stronger resistance against moisture or chemicals, materials will need to advance in order to combat any sort of change in the climate.

Figure E2. Potential Effects of Climate change on buildings (Snow 2011, p 2).
Figure E3. Weather related catastrophes, 1950-2004 (Snow 2011, p. 4).

This figure shows how the climate has impacted on an increase in natural disasters in the last half-century. Materials will need to adapt to become more resilient to these types of intense events.
Appendix F - Author's Co-related reports

‘What will be the predominant engineering materials and procedures used in sustainable infrastructure in 2030’

Tom Murrell’s Response

History shows that the progression of ancient civilisations has been to some degree, a result of their advancements with materials. This is evident throughout history where the ages of man where named after the dominant material of the day. During the industrial revolution and over recent years technology has rapidly advanced leading to mass production, giving man a consumption capability absent of that of his ancestors. This has allowed for greater population growth and a better standard of living, but as we are coming to realise has greatly jeopardised the sustainability of future generations. This has led to the investigation into sustainable infrastructure and the implementation of ‘cleaner’ engineering materials and procedures.

Some 300 years ago the human race was living a completely sustainably lifestyle. Advancements in human activity have seen it become completely dependent on non-renewable resources by the end of the 20th century. The Earth does have a large reserve of resources however they are not infinite as the past perception has eluded too. The increased demand for materials and energy, combined with the exponential population growth (see figure 1) and living conditions of some people have led to a great concern for the sustainability of the earth. In fact ‘At a growth rate of just 3% per year, we will mine, process, and dispose of more “stuff” in the next 25 years than in the entire 300 years since the start of the industrial revolution’ (Ashby, 2013, p32).

Given the increased investigation into the effects of climate change, along with the fact that ‘more than ¾ of all the materials scientists and engineers who have ever lived are alive today,’ (Ashby, 2013, p6) It is clear that the pursuit to develop more sustainable materials and procedures is inevitable. In the next few years we are likely to see a reduction in non renewable energy sources (fossil fuels 86% of total energy currently) and a greater shift to renewable energies.

Commodity prices will increase due to the increase costs of carbon taxes/ initial capital costs of renewable energy sources needed to mine the materials. Scarcity of
current predominant engineering materials will also result in an increase in price. With this increase mining companies may be able to fund more advanced exploration using improved extraction technology to discover more mineral reserves within the earth’s resource previously ‘out of reach’ (see figure 2), or begin to automate current processes resulting in future workforce savings. This will only be a quick solution to the growing problem and is essentially only buying limited time as ‘growth is the life blood of today’s consumer driven economies’ (Ashby, 2013, p16).

New materials and processes requiring the least impact to the environment at a reasonable cost will need to be developed. We are currently moving through the molecular age (nanotechnology) post 2000 and thus now have analytical tools capable of resolving and manipulating matter at the atomic level. This can essentially allow us to ‘build’ materials from the molecular level with specific properties, enhancing our design capabilities. At present there are still questions about its environmental impact however by 2030 I believe that we will start to see the integration of more of these Nano-materials into engineering practices similar to that seen with carbon fibre in the past 30 years. My predictions for 2030 can be seen in figure 4, which show predominant materials for both now (Ashby, 2013) and that predicted for 2030. Affordability may present an issue and so the task to implement such a change will need to have some economic benefit, predominantly from a government incentive.

The option to recycle engineering materials on a larger scale to that of present should not be overlooked. Waste too like population is also being generated at an increasing rate. It is a viable option to return materials back into the supply chain, having comparable costs to that of raw material generation. In developed countries this is becoming common practice for used materials such as metals and polymers; however this should be implemented to a much larger scale globally.

Biomaterials such as wood and bamboo may provide an environmentally friendly alternative option for small scale construction projects where it can substitute for concrete; however, it design life will be less and like all organic material its properties are highly variable and only suitable for specific tasks. Never the less with greater emphasis on the design stage and further considerations into the appropriate
material being selected for a specific application; this could be a viable option in other parts of the world where biomaterials are currently absent.

The main drivers for material development in the past have been a result of defence. Given the current situation of climate change, the rapid growth of societies and increasing scarcity of resources the world is becoming unstable. Conflicts throughout are evident and thus resources and their security is and has been a key target. This is a growing problem which greatly complicates any complete global solution for future sustainability.

Locally and to some degree internationally legislation will play a large part in changing current procedures of companies greatly influencing the materials/construction sectors. This legislation needs to mitigate environmental impact by looking at both the energy and emissions involved with material generation and current procedures. Economic incentives should be provided to fund research and compensate for initial costs of converting to clean energy processes and environmentally friendly materials.

Per capita consumption in developed countries is beginning to stabilize, however in emerging economies it is growing much more quickly. The material consumption for the 25 most populous nations can be seen in figure 3. This consumer attitude, should it not significantly change will also be a main driver for change in not only current materials and procedures, but in living conditions as well.

By 2030 the world will be vastly different to what we see it today. Waste will not be discarded but recycled at a larger scale than that experienced currently. Majority of energy will come from renewable sources; the efficiency of material processes will be greatly increased and advancements in material development will see stronger more environmentally friendly alternative materials being integrated into common engineering procedures. The predominant engineering materials in 2030 will be similar to that of current however focused more so on minimising environmental impact as shown in figure 4. I believe that this will be achieved by 2030 through developments mainly in nanotechnology but also further investigations into sustainability.
Figure 1. illustrates the population exponential relationship for the last 2000 years. This figure was taken directly from; Ashby, 2013, figure 1.3 p 9.

Figure 2. shows the distinction between reserves and the resource base; Ashby, 2013, figure 2.14 p 33.
Figure 3 shows the population of the 25 most populous countries in the World. This figure was taken directly from; Ashby, 2013, figure 1.4 p 10.

Figure 4. shows the 27 current predominant materials industrialized society depends on as given by Ashby, 2013, figure 2.3, p 19. In addition to Ashby’s diagram the black dots depicted in line with each material represent its predicted magnitude of production in 2030. Note that the metals have
decreased due to more recycling/ efficient design through nano technology, as has majority of the energy intensive ceramics, namely concrete.

References:

Jemily Sweet's Response

In the last decade we have seen rapid development in inorganic chemistry, that is, how materials behave and are further developed. Due to this rapid development and the increasing population, society has got to the stage where they are totally dependent on these materials that consume resources that cannot be replaced (Ashby 2009). Engineering materials include iron, copper, tin, zinc, steel, ceramics and polymers which are consumed globally at a rate of ten billion tonnes a year (Ashby 2009). Current procedures and processes to develop these materials are highly energy inefficient and globally we consume 500 billion billion joules (EJ) with 86% of that consumption being sourced from fossil fuels (Ashby 2009). It is widely known that fossil fuels have a negative effect on the environment as pollutants get trapped in our atmosphere and contribute to the global warming effect. To maintain the lifestyles we live in and develop sustainable infrastructure it is imperative that changes in the way materials are manufactured, used and disposed of are initiated through renewable energy sources such as solar, wind and thermal. In terms of global modern industry, sustainability refers to the various infrastructural, organisational and behavioural changes associated with a move to a renewable energy foundation (Holmgren 2013).

Drivers for the change we need to develop practices and materials different to the current modes include but are not limited to, the diminishing land resources, population growth, climate change and the unpredictable economy. Most materials are made from minerals of the Earth's land and oceans and a reduction of these resource bases can be detrimental for both the environment and economy (Ashby 2009). One of the most consumed resources in the world for the manufacture of materials is oil, which is produced in only few countries, which means if the demand exceeds supply the dependence on this commodity will greatly affect global economies that rely on it (Ashby 2009). Governments can play a large role in implementing this change, with economic instruments such as green taxes, subsidies, trading schemes and encourage people to buy local products (Ashby 2009).

Embodied energy (non renewable energy consumed in acquiring the materials, process, manufacture, maintain, replace during the life of the material) for steel, aluminium and copper are high when compared to other materials such as wood (Ashby 2009). The recycling energy of metals such as steel is small compared to the initial embodied energy which makes recycling an energy efficient substitute. Although, recycled materials have significant property differences to their original state there is enough uses for them to be an effective material (Ashby 2009). If recycling technology advances it could include polymers.
and be able to increasingly be effective in the way recycling consumes energy and be incorporated into infrastructure in the future. An ideal attribute of a material is for it be drawn from a source that is renewable, either because it grows as fast as we use it or because it naturally decays in a timely manner (Ashby 2009). One of the materials that stands out is wood, as it can be harvested and grown at the same time. Consequently, to be effective in the construction industry wood is cut and not replaced, chemically treated and transported with non renewable resources, although it is far more renewable than metals (Ashby 2009). Other sustainable materials that may be predominantly used in 2030 include rammed earth and adobe (soil, straw and lime cement) which can be used for walls and bricks that have high heat capacity (keeps the inside cool in the day and warm at night) (Ashby 2009). In addition, stone (fieldstone) and lime when incorporated is robust and durable and can be used effectively and renewably as fences (Ashby 2009).

In terms of processes and procedures the transportation of the materials is a large contributor to their overall non renewable properties. Manufacturing is worldwide and products are made where it is economical to do so and then transported, commonly over great distances (Ashby 2009). In addition, when ready to be assembled or constructed heavy machinery that run on fossil fuels are used extensively in the construction. Looking to 2030, machinery could be running on renewable sources such as solar and people are far better informed and source local products to cut energy consuming transportation.

The Earth's crust has many elements that we currently use in large quantities such as aluminium and iron, although it is the energy use that is affecting our resource bases (Ashby 2009). The material change relies heavily on technology, science and governments continual development in non polluting and cheap energy sources that equal that of burning fossil fuels. In the case where renewable energy is still in development by 2030, utilising sustainable materials and processes such as recycled materials, utilising wood, straw, stone, soil and source local products will help adapt to changes that are hopefully foreseeable in the future. At this present time we are reaching limits on the way we use fossil fuels for energy and Earth's resources for materials and it is hopeful that by 2030 infrastructure will be sustainable to the point where near all materials are renewable.

References:
Jackson Renton's Response

“All human activity has some impact on the environment in which we live” (Ashby 2009, p. 7). Various studies have shown that current consumption of resources by humans is not sustainable for the future. Therefore, in order to allow a future for human kind, changes to the way in which we use resources must be made. As the population grows, as well as the economy, so does the demand for energy and materials. Unfortunately while the amounts are very large, these resources are not infinite, meaning at some point, current materials and engineering procedures will need to change.

Dependence on resources has “over time... progressively changed from a reliance on renewable materials – the way mankind existed for thousands of years – to one that relies on materials that consume resources that cannot be replaced” (Ashby 2009, p. 7). Looking back into the past of human history, humans were able to live harmoniously with the environment without harming it. “Simple but remarkable structures could be built from the materials of nature: stone and mud bricks for walls, wood for beams, rush and animal skin for weather protection” (Ashby 2009, p.2). Energy use was low and Technological advances throughout this history rendered other products obsolete. With each new discovery, the new material was able to perform a role better than the last.

Western culture is so dependent on material use that almost all activities we do requires some sort of material use. Presently, the “materials of engineering have a life cycle” (Ashby 2009, p. 39). That is, they are taken from raw resources and processed until they are ready for transport and use and finally disposed of. The idea is they are recycled to maintain the ‘life-cycle’. This process of allowing us to create usable products from basic raw materials uses energy, and a lot of it. This is creating problems for the environment as we are using this energy and resources in an unsustainable manner, the most significant consequence being climate change and the distinct possibility of running out of certain resources. As shown in figure 1, the most used materials in modern practice are oil & coal, concrete and wood. Currently, the practice for materials no longer meeting their functional needs can be placed into five categories; “landfill, combustion, recycling, reengineering, or reuse” (Ashby
2009, p. 65). The re-engineering, recycling or reuse components are aimed at sustainable living through saving resources and energy.

No-one can predict how the world will look in the year 2030, however, we can make educated assumptions based on the past. Due to the current environmental impacts humanity imposing on the Earth, it could be assumed that at some point in the next 15 years, great reductions in energy and resource consumption will be required. Some of the drivers of change for this could include a shift in the economy to a less capitalist and western way of thought. This would promote conservation and less growth not necessarily being uncomfortable. Another driver of change could be advances in technology. In the last 5 years alone there have been significant innovations in technology that would have seemed impossible just years before they were discovered. Who knows what is possible in the next 15 years and what could be achieved to reduce the current stress on the environment and its resources. Rising costs in fuel, transportation and labour could make projects unviable to continue or start. Depletion of resources could impact heavily on how the future will look and what resources will be in use. Suitable innovative substitutes will need to replace current resources in jeopardy of being lost.

The final impact that will affect the future and its engineering procedures and materials, and possibly the most influential, will be government policy and pressure. If governments stand by the environment and fight for current methods to be changed in order to secure a future for humanity, then anything could be possible. The real question will be how much are they willing to change. For fear of not being re-elected, it is possible that there will be no new radical changes to current legislation. However, if the environment and sustainable living are lifted to a new level of importance then it may be possible to see a very different landscape in the future. Examples of political efforts to create a more sustainable way of life involve The Montreal Protocol, The Kyoto Protocol and more recently, the carbon emission tax. Figure 5. Below demonstrates many different factors which are assumed will create a change by the year 2030. It is comprehensive in its list of various factors which will impact, some of which have been detailed above.

Processes of creating goods and services will need to change from high energy and resource intensive to one of a low energy and resource consumption. Society will
need to be educated as to ways in which they can contribute, as simply as choosing one product as a near perfect substitute for another. New materials will be formed out of necessity as humans are great at adapting and creating new methods of doing things. Nano-technology and carbon fibre will be advanced to create new methods of construction as well as a greater use for renewable resources such as timber and stone (virtually renewable due to an almost infinite amount available).

Sustainable energy will be adopted in the future due to less resources being available and prices increasing. Sustainable options such as; wind, solar, hydro, waves, tidal and geothermal will all be viable and preferred options for power in 2030. Other factors which will need to be considered are; water use, land use, climate change and national security. Figure 3 demonstrates just how one sided the energy production is in terms of resources being consumed.

The year 2030 will look vastly different to the world we know today. A new age of sustainable living will be introduced whereby energy is created from renewable resources, advances possibly not yet conceived or thought possible will be providing new materials for infrastructure and recycling, reuse and re-engineering will be normal practice. This thought may be ‘radical’, but it will also be necessary to provide security for the future generations of humankind to come. The size of the impact of the driving forces will determine how different the world will look by the year 2030 and whether humanity is striving to reach sustainable living.
materials most used by humans (Ashby, M 2009, p. 17).

Figure 2. A pie chart of the families of materials used (Ashby, M 2009, p. 18).
Figure 3. Energy consumption by humans in 2005 (Ashby, 2009, p. 19).
Figure 4. Resource consumption and its drivers (Ashby, M 2009, p. 20).
Figure 5. Factors which will create change for the future (Ashby, M 2009, p.257).

References

Ryan Griffin’s Response

Over many occasions in Earth’s lifetime, history has repeated itself. This can most certainly be applied in relation to the way society is operating and developing presently. As a primitive race, humans relied upon the Earth’s natural resources to live and grow. Although nothing has changed in the sense that humans still harness the Earth’s natural resources, it’s how humans are now using these resources and their dependency upon them which is of concern (Ashby 2009).

Humans have developed far beyond their ancestors and how they lived, through technological and social advancements. The numbers of humans living on the planet has also increased drastically, creating greater stress on resources and the system as a whole. As a result the planet’s supplies have been exploited and a shift towards use of non-renewable resources has been seen. Whilst the Earth is relatively large in size compared to its inhabitants, its resource supply is not endless and will eventually be exhausted. This particularly applies to materials that require thousands or millions of years to form, which are most certainly not renewable. Since awareness for the position the Earth is in and the need for sustainability has increased, a swing back to renewable materials and resources can be noted.

There are many reasons for why humans need to revert to ways which closer mimics those of ancestors, only with a modern twist. These reasons include: preserving the Earth’s natural resources, promoting a healthier state of living for society and of course the sustainability of the human race, ensuring future generations have somewhere to live.

These goals can be met through many different drivers. The primary driver is climate change and that the Earth is actually being affected by human behaviour no matter the activity being carried out (Ashby 2009). Climate change and the ‘health’ state of the planet will force governments to push policy and legislation, even if it is outside political interests and popularity. This will put particular restrictions on manufacturing, energy companies as well as consumers.

A major driver is also the economy and will be particularly relevant in bringing the needed change to the public eye. The primary resource which this will be most relevant for is oil. The price of oil is going to increase drastically as 2030 approaches
due to it becoming more scarce. This price increase will significantly affect the entire first world population. Everything is connected to oil either through its production, operation or being.

2030 will see many changes to current materials and how they are used. There will be new innovative and highly sustainable materials discovered, such materials as graphene or aerogel, which are highly innovative for present times. Materials already in use such as biomaterials, polymers and nanotechnology hold promise for the future. Biomaterials and polymers will seek to replace all existing non-renewable and unsustainable plastic products. Polymers are likely to be used in more structural applications whereas biomaterials will be used in consumer and medical plastics.

Predicting the future is never a simple process and nothing is certain when making forecasts. That said, relying on current trends and systems and where society appears to be heading, some approximations can be made. It is clear that sustainability is going to take a key role in the next few decades as pass by. Governments are going to increase the presence of sustainability in their policies and legislation and in turn this will affect everyone. All infrastructure comes from the materials it was made from and so sustainability must be achieved at all levels of product processes and not just in the operation.