ENERGY TRANSFORMED:
SUSTAINABLE ENERGY SOLUTIONS FOR CLIMATE CHANGE MITIGATION

MODULE B
INTEGRATED SYSTEMS BASED APPROACHES TO REALISING ENERGY EFFICIENCY OPPORTUNITIES FOR INDUSTRIAL/COMMERCIAL USERS – BY SECTOR

This online textbook provides free access to a comprehensive education and training package that brings together the knowledge of how countries, specifically Australia, can achieve at least 60 percent cuts to greenhouse gas emissions by 2050. This resource has been developed in line with the activities of the CSIRO Energy Transformed Flagship research program, which is focused on research that will assist Australia to achieve this target. This training package provides industry, governments, business and households with the knowledge they need to realise at least 30 percent energy efficiency savings in the short term while providing a strong basis for further improvement. It also provides an updated overview of advances in low carbon technologies, renewable energy and sustainable transport to help achieve a sustainable energy future. While this education and training package has an Australian focus, it outlines sustainable energy strategies and provides links to numerous online reports which will assist climate change mitigation efforts globally.

CHAPTER 5: ENERGY EFFICIENCY OPPORTUNITIES IN LARGE ENERGY USING INDUSTRY SECTORS

LECTURE 5.1: OPPORTUNITIES FOR ENERGY EFFICIENCY IN THE ALUMINIUM, STEEL AND CEMENT SECTORS
The Natural Edge Project (TNEP) is an independent non-profit Sustainability Think-Tank based in Australia. TNEP operates as a partnership for education, research and policy development on innovation for sustainable development. TNEP's mission is to contribute to, and succinctly communicate, leading research, case studies, tools, policies and strategies for achieving sustainable development across government, business and civil society. Driven by a team of early career Australians, the Project receives mentoring and support from a range of experts and leading organisations in Australia and internationally, through a generational exchange model.
The International Energy Agency forecasts that if policies remain unchanged, world energy demand is set to increase by over 50 percent between now and 2030. In Australia, CSIRO has projected that demand for electricity will double by 2020. At the same time, The Intergovernmental Panel on Climate Change (IPCC) has warned since 1988 that nations need to stabilise their concentrations of CO₂ equivalent emissions, requiring significant reductions in the order of 60 percent or more by 2050. This portfolio has been developed in line with the activities of the CSIRO Energy Transformed Flagship research program; ‘the goal of Energy Transformed is to facilitate the development and implementation of stationary and transport technologies so as to halve greenhouse gas emissions, double the efficiency of the nation’s new energy generation, supply and end use, and to position Australia for a future hydrogen economy’. There is now unprecedented global interest in energy efficiency and low carbon technology approaches to achieve rapid reductions to greenhouse gas emissions while providing better energy services to meet industry and society’s needs. More and more companies and governments around the world are seeing the need to play their part in reducing greenhouse gas emissions and are now committing to progressive targets to reduce greenhouse gas emissions. This portfolio, The Sustainable Energy Solutions Portfolio, provides a base capacity-building training program that is supported by various findings from a number of leading publications and reports to prepare engineers/designers/technicians/facilities managers/architects etc. to assist industry and society rapidly mitigate climate change.

The Portfolio is developed in three modules;

**Module A: Understanding, Identifying and Implementing Energy Efficiency Opportunities for Industrial/Commercial Users – By Technology**

Chapter 1: Climate Change Mitigation in Australia’s Energy Sector

Lecture 1.1: Achieving a 60 percent Reduction in Greenhouse Gas Emissions by 2050
Lecture 1.2: Carbon Down, Profits Up – Multiple Benefits for Australia of Energy Efficiency
Lecture 1.3: Integrated Approaches to Energy Efficiency and Low Carbon Technologies
Lecture 1.4: A Whole Systems Approach to Energy Efficiency in New and Existing Systems

Chapter 2: Energy Efficiency Opportunities for Commercial Users

Lecture 2.1: The Importance and Benefits of a Front-Loaded Design Process
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Chapter 3: Energy Efficiency Opportunities for Industrial Users

Lecture 3.1: Opportunities for Improving the Efficiency of Motor Systems
Lecture 3.2: Opportunities for Improving the Efficiency of Boiler and Steam Distribution Systems
Lecture 3.3: Energy Efficiency Improvements available through Co-Generation

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**Module B: Understanding, Identifying and Implementing Energy Efficiency Opportunities for Industrial/Commercial Users – By Sector**

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Lecture 4.2: Demand Management Approaches to Reduce Rising ‘Peak Load’ Electricity Demand
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Lecture 4.4: Making Energy Efficiency Opportunities a Win-Win for Customers and the Utility: Decoupling Energy Utility Profits from Electricity Sales

Chapter 5: Energy Efficiency Opportunities in Large Energy Using Industry Sectors

Lecture 5.1: Opportunities for Energy Efficiency in the Aluminium, Steel and Cement Sectors
Lecture 5.2: Opportunities for Energy Efficiency in Manufacturing Industries
Lecture 5.3: Opportunities for Energy Efficiency in the IT Industry and Services Sector

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**Module C: Integrated Approaches to Energy Efficiency and Low Emissions Electricity, Transport and Distributed Energy**

Chapter 7: Integrated Approaches to Energy Efficiency and Low Emissions Electricity

Lecture 7.1: Opportunities and Technologies to Produce Low Emission Electricity from Fossil Fuels
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Lecture 7.4: Hidden Benefits of Distributed Generation to Supply Base Electricity Demand

Chapter 8: Integrated Approaches to Energy Efficiency and Transport

Lecture 8.1: Designing a Sustainable Transport Future
Lecture 8.2: Integrated Approaches to Energy Efficiency and Alternative Transport Fuels – Passenger Vehicles
Lecture 8.3: Integrated Approaches to Energy Efficiency and Alternative Transport Fuels - Trucking

Chapter 9: Integrated Approaches to Energy Efficiency and Distributed Energy

Lecture 9.3: Beyond Energy Efficiency and Distributed Energy: Options to Offset Emissions
Energy Efficiency Opportunities in Large Energy Using Industry Sectors

Lecture 5.1: Opportunities for Energy Efficiency in the Aluminium, Steel and Cement Sectors

Educational Aim

The Aluminium, Steel and Cement Sectors are significant contributors to greenhouse gas emissions. Hence the educational aim for this lecture is to provide an overview of the energy efficiency opportunities in the aluminium, steel and cement sectors, and to provide access to the best online resources, outlining in detail the energy efficiency opportunities for each sector.

Essential Reading

Reference                      | Page |
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5 Peer review by Adjunct Professor Alan Pears – RMIT.
Learning Points

1. The aluminium, steel and cement sectors are three of the highest energy using and greenhouse gas producing sectors in Australia, and hence there are opportunities to achieve significant energy efficiency reductions. For instance, the aluminium sector contributes 16 percent of the greenhouse gas emissions from the electricity sector and 6.5 percent of Australia’s greenhouse gas emissions in total.

2. The aluminium industry is comprised of several quite different sub-industries – bauxite mining, the alumina refining industry and the aluminium smelting industry. Greenhouse gas emissions the aluminium industry is dominated by the smelting process rather than the bauxite mining and alumina refining. While Australian bauxite mining and alumina refining are similar in greenhouse gas intensity (the ratio of greenhouse gas emissions to economic output) when compared to world’s leading practice, our smelting emissions are well above world average due to the high greenhouse intensity of the electricity used, indeed, Australian smelters rate well globally on their on-site emissions.

3. In Australia, bauxite is mined exclusively using the open-cut method. After removing the top-soil and overburden, ore breaking is undertaken by the drill-and-blast method, or ripping. Ore is then excavated using front-end loaders or hydraulic excavators and hauled by trucks. Crushing of the ore usually takes place at the mine-site. The energy efficiency opportunities for this sector are as follows:
   a. Design and gradients of haul routes.
   b. Logistical planning of mine face activity to minimise haul distances.
   c. Optimisation of blasting and ripping techniques in terms of reducing the milling requirement by increasing the use of cost-effective solar applications.
   d. Fuel recording and maintenance practices (condition monitoring) that optimise the fuel efficiency of haul trucks, including:
      - Low-cost engine upgrades and comparison between different truck types. Use of hybrid electric trucks offers potential emissions and operating cost reductions.
      - Recording of fuel use to provide information which is used to determine when particular trucks should be sent for dynamometer testing and servicing to restore fuel efficiency to design levels.
      - Driver performance in relation to fuel efficiency.
      - Recording and monitoring of research and development (R&D) support to help truck manufacturers to develop larger, lighter, more fuel-efficient vehicles.

4. Bauxite is refined into alumina using the Bayer Process. Major improvements in the energy efficiency of bauxite refining can be achieved by:
   - Improving thermal efficiency, including reduction of heat losses from pipes and calciners.
   - Improving the compressed air systems.
   - Replacing the rotary kilns with gas suspension calciners.
- Optimal use of cogeneration (in WA, Alcoa and Alinta have partnered in a sophisticated cogeneration project, so that the refineries are net exporters of very low greenhouse impact electricity to the grid)
- There is also potential for use of gas engine driven grinders, with the waste heat being used in the process

5. Primary aluminium is produced by the Hall-Heroult process; the electrolysis of alumina dissolved in a molten cryolite-based electrolyte. Electric current is used to separate the alumina into aluminium and oxygen. Within smelters, a number of developments offer significant potential for energy efficiency savings, including:
- Improved smelter fume systems and heat recovery.
- Improved compressed air systems.
- Inert anodes to replace carbon anodes.
- Drained cathodes can cut electricity use by up to 20 percent.⁶
- Heat recovery; since pot lines run at close to 1,000°C, there is a large amount of heat available to be recovered through co-generation.

6. The basic process of making steel has several phases to it. The Steel University⁷ has created an online technical manual outlining these processes in detail, and at each stage of the process there are energy efficiency opportunities. Martin⁸ et al⁹ and Stubbles,¹⁰ covered these opportunities in detail in their papers on the iron and steel sectors (see Essential and Optional Further Reading). In the steel industry there are a range of energy efficiency and recycling opportunities to significantly reduce the carbon footprint of this sector. Significant opportunities exist through co-generation, advanced and high efficiency electricity generation technology, advanced electric furnace design like himstelt, and steam and gas recovery systems

7. Cement is now responsible for 6 percent of global greenhouse gas emissions; an 8 fold increase globally since the mid 60s.¹¹ Large quantities of CO₂ are emitted during the production of lime, the key ingredient in cement. Lime, or calcium oxide (CaO), is created by heating calcium carbonate (CaCO₃) in large furnaces called kilns, and calcium carbonate is derived from limestone, chalk, and other calcium-rich materials. The process of heating calcium carbonate to yield lime is called calcination or calcining and is written chemically as: CaCO₃ + Heat → CaO + CO₂. 0.534 tons of CO₂ per ton of cement is produced by this chemical process, in addition to the emissions from fossil fuel used to drive it. Lime combines with other minerals in the hot kiln to

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⁹ See Essential and Optional Further Reading
form cement’s active ingredients. There are a wide range of energy efficiency opportunities in this sector outlined in papers by Worrell et al.16 and summarised in Table 5.1.2.

8. In Australia, the Cement Industry Federation stated that in 2004, ‘30 percent of the cost of manufacture of cement is fuel and electricity. Since 1990 energy consumption in the cement industry has reduced by 16 percent in power and 27 percent for fuel per tonne of production of cement. Should the scope broaden to include cementitious material (fly ash and slag) sold by the industry, energy consumption has reduced by 18 percent for power and 28 percent for fuel.’13 The main areas of improvement to date in the Australian cement industry have been:

- Investment in dry precalciner kilns, which require more than 30 percent less energy to operate than a wet kiln, per ton of product.

- Utilising ‘waste’ products (waste tyres, demolition timbers, waste oil, carbon anode dust, aluminium spent cell liners, solvent based fuels etc.) as a source of fuel for the kilns instead of coal or gas. It is important to note that, where these waste products are made from fossil fuel feedstocks and would have otherwise remained inert in landfills, then the amount of CO2 released by using them is not reduced relative to direct use of fossil fuels – indeed it can be increased.

- Smaller technological improvements that can and have been made during the shut down periods that usually occur annually. These improvements include upgrades to fans, installation of high efficiency classifiers on grinding mills, improved burner technology, use of electronic surveillance and control of the entire manufacturing process.

- Investment in cement grinding to reduce electrical energy consumption.

9. Another way to significantly reduce greenhouse gas emissions is to use blast furnace slag and fly ash to replace a proportion of Portland cement. This approach reduces the embodied energy as they are cementitious and involve much less energy to produce. They reduce greenhouse gas emissions both through reduced energy use and reduction in the quantity of process CO2 from calcination per ton of final product.

10. Since there are limits to which CO2 can be reduced from this traditional approach to making cement scientists and engineers are now researching new ways to make cements. One very promising alternative to traditional cements is geo-polymers. Geopolymeric cements set quickly, are at least as strong as traditionally made cements, last longer, and are more resistant to fires.14 They can be cheaply made based on several types of clay and industrial waste and a few common sedimentary rocks. Geopolymeric cements can be formed at much lower temperatures than Portland cement (and the chemical process does not require CO2 to be produced, thus resulting in a 80-90 percent decrease in CO2 produced during its fabrication.15 According to CSIRO, geopolymers can be used for every major purpose for which Portland cement is currently used.16

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11. Magnesium cements are still in a relatively early development phase but deserve further investigation. Through a blend of magnesium oxide and conventional cement, Australian inventor John Harrison of TecEco Pty Ltd. developed ‘eco-cement’. This new blend of cement incorporates magnesium oxide (magnesia) and wastes to make it environmentally sustainable. Eco-Cement uses a lower heating temperature during manufacturing, so less fossil fuels are used. Wastes such as fly and slags etc. can be included, without incurring problems such as delayed reactions. Eco-Cement absorbs CO$_2$ from the atmosphere to set and harden and can be recycled.\textsuperscript{17}

Brief Background Reading

The Global Aluminium Industry Voluntary Sustainable Development Program

The International Aluminum Institute publishes a survey of global energy consumption every year, which has, over the years, recorded a considerable reduction in energy consumption per ton of aluminium produced. In the 1990s, smelters used a third less electricity per ton than the equivalent plant in the 1950s, and that trend of improving energy efficiency is continuing. In 2003, the Future Generations Sustainable Development Program was launched by the International Aluminum Institute\(^{18}\) (IAI) in partnership with the regional and national aluminium associations. The program is a voluntary global undertaking by the members of the IAI, involving 26 CEOs, whose companies represent over 75 percent of the world’s aluminium production. The International Aluminum Institute’s program outlined eight voluntary objectives and twenty-two performance indicators, which were designed to encourage a continual improvement in performance by the industry.\(^{19}\) The following outlines the objectives and indicators related to the greenhouse gas reduction goals:

1. **Voluntary Objective 1**: An 80 percent reduction in perfluorocarbon (PFC) greenhouse gas emissions by 2010, from 1990 levels, for the industry as a whole per ton of aluminium produced. [Between 1990-2003 PFC specific emissions (per ton of aluminium produced) were reduced by 73 percent globally. In Australia some aluminium companies have reduced PFC emissions by 90 percent.\(^ {20}\)]

2. **Voluntary Objective 3**: A 10 percent reduction in smelting energy usage by 2010, from 1990 levels, for the industry as a whole per ton of aluminum produced. [Since 1990 the average electric energy used for electrolysis has been cut by 6 percent.]

3. **Voluntary Objective 7**: A reduction in greenhouse gas (GHG) emissions from road, rail and sea transport through the industry’s annual monitoring of aluminium shipments. Also the industry will track aluminium’s contribution through light-weighting of products and consequent savings in transport fuel for owners of aluminium products. [Between 2002-2003 aluminium shipments to the automotive and light truck industry increased by 5.5 percent.]

In addition to this, the Asia Pacific Partnership for Clean Development and Climate (AP6) involving Australia, US, China, Japan, South Korea and India, has initiated an Aluminium Taskforce to share knowledge on how to reduce greenhouse gas emissions in this sector.\(^ {21}\) There is significant international attention on these issues from which the Australian Aluminium industry can benefit.

The Australian Aluminium Industry

The aluminium industry is the single largest industry sector consumer of electricity in Australia, accounting for about 15 percent of industrial consumption. It is also a large consumer of natural gas, fuel oil, coal and distillate in alumina refining and bauxite mining. The aluminium industry is comprised of several quite different sub-industries – bauxite mining, the alumina refining industry and the aluminium smelting industry. Currently, energy consumption per ton of alumina in Australia is

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12,269 MJ/t, compared to world’s best practice of 9,000 MJ/t achieved by the German company AOS38. In the late 1990s, alumina sales generated slightly more export income than aluminium sales. Although in 2003 export value was similar for the two products, ABARE has recently reported that “Australia’s alumina export earnings in 2006-07 are estimated at $6.3 billion, 20 per cent higher than in 2005-06, reflecting high export prices and volumes. In 2006-07, Australian export earnings from aluminium are estimated to have increased by around 20 per cent to $5.7 billion.” Alumina refining is generally located near bauxite deposits, and requires mostly heat, and a small amount of electricity.

Bauxite Mining

In Australia, bauxite is mined exclusively using the open-cut method. After removing the top-soil and overburden, ore breaking is undertaken by the drill-and-blast method, or ripping. Ore is then excavated using front-end loaders or hydraulic excavators and hauled by trucks. Crushing of the ore usually takes place at the mine-site. Total energy used in bauxite mining in Australia in 1998 was 2PJ, costing the industry AUD$20 million. Energy cost per ton of bauxite as mined is AUD$0.50. If all mining sites operated at the energy efficiency of the lowest energy using bauxite mine (40MJ/ton), a reduction of about 11 percent, representing AUD$2 million a year, might be achieved. Opportunities that for energy efficiency improvement in bauxite mining include:

- Design and gradients of haul routes.
- Logistical planning of mine face activity to minimise haul distances.
- Optimisation of blasting and ripping techniques in terms of reducing the milling requirement by increasing the use of cost-effective solar applications.
- Fuel recording and maintenance practices (condition monitoring) that optimise the fuel efficiency of haul trucks, including:
  a. Low-cost engine upgrades and comparison between different truck types.
  b. Recording of fuel use to provide information to determine when particular trucks should be sent for dynamometer testing and servicing to restore fuel efficiency to design levels.
  c. Driver performance in relation to fuel efficiency.
  d. Recording and monitoring of research and development (R&D) support to help truck manufacturers to develop larger, lighter, more fuel-efficient vehicles.
  e. A shift to hybrid electric trucks.

Aluminium Refining

Bauxite is refined into alumina using the Bayer Process. First the bauxite is ground and dissolved in sodium hydroxide (caustic soda) at high pressure and temperature in a process called digestion; a solution of sodium aluminate and undissolved bauxite residues. The residue or ‘red mud’ sinks gradually to the bottom of the tank and is removed (clarification). The sodium aluminate solution is

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24 Ibid.
then pumped into a tank called a precipitator. Fine particles of alumina are added to seed the precipitation of alumina particles as the liquor cools (precipitation). The particles sink to the bottom of the tank and are removed, filtered and washed. This process typically uses low temperatures which can, for instance, be supplied by waste heat from a cogeneration plant. A high temperature calciner is then used to drive off moisture and chemically combined water (calcination). The result is a white powder called alumina.

It takes about two tons of alumina to produce one ton of aluminium. Over 90 percent of the world’s alumina is used for making aluminium. The balance is used in the chemical, refractory and abrasives industries. The majority of energy consumed in alumina refineries is in the form of steam used in the main refining process. In Australia this steam is produced by burning either gas, coal or fuel oil. Significant fuel switching to gas has now occurred and/or is occurring within the Australian alumina sector towards gas. The theoretical energy requirements of alumina refining are significantly lower than the energy now used. The theoretical energy requirement for calcination is 1.7 GJ/ton,26 while world’s best practice is around 3 GJ and the Australian average is 3.9 GJ. Major improvements in energy efficiency can be achieved by:

- **Improving thermal efficiency:** Large amounts of low temperature heat is used in the digestion process (before calcination), and heat recovery, cogeneration and solar thermal offer the potential to reduce overall energy use in this part of the process. Thermal energy efficiency improvements are possible in individual processes such as heat exchange into slurries, the digester process, alumina calcination, and evaporation, as well as through reduction of other losses through, for example, improved pipe and tank insulation and protection of hot equipment from wind and rain. Energy efficiency can also be improved by the development of advanced optimisation strategies to improve the balancing of energy usage against other factors. When useful heat is required, replacing some large electric motors with gas engine drives with heat recovery can offer benefits.

- **Improving compressed air systems:** The production and generation of compressed air is widely recognised as an area where there are opportunities for improvement in a wide range of industries including the aluminium industry.

- **Replacing rotary kilns with gas suspension calciners:** This technology has the potential to improve energy efficiency, i.e. by recovering heat (co-generation) for use in other processes.

A key opportunity in this industry is cogeneration. Most of the energy required for alumina refining is heat, and much of this energy could be provided by cogeneration. Previously, electricity utility policies have discouraged alumina refineries from optimising the balance of energy supply, because this would require them to export substantial amounts of excess electricity. With energy market reform, this situation is changing. Alcoa’s WA refineries, for example, have negotiated an arrangement with Alinta to supply excess electricity from cogeneration to the grid. This electricity has low greenhouse intensity compared with conventional power generation, so its economics improve when a price is levied on CO₂ emissions.

Alumina production is also well-suited to use renewable energy, through options such as solar reform of natural gas, biogas, biomass and solar thermal. In the medium term, efficiency improvements and increased cogeneration offer substantial opportunity to cut primary energy use in the alumina industry by at least 30 percent. In the longer term, much more aggressive efforts to minimise heat

loss, heat recovery techniques and renewable energy sources will be important for ongoing improvement.

**Aluminium Smelting**

Primary aluminium is produced by the Hall-Heroult process; the electrolysis of alumina dissolved in a molten cryolite-based electrolyte. Electric current is used to separate the alumina into aluminium and oxygen. Alumina itself is produced from bauxite ore feedstock in a thermal digestion process. Scrap pre-treating and melting to produce secondary aluminium takes place in fuel-fired (or occasionally electric) furnaces.

Aluminium smelting can be located anywhere there is cheap, reliable electricity and a suitable port. It uses mostly electricity, although it also requires some heat. Electricity intensity of electrolysis at present in Australia is 13-15 MWh/t of aluminium, which is over twice the absolute theoretical limit of 6.34 MWh/t. A realistic eco-technical potential is 10-11 MWh/t, which will require the use of new materials and improved pot design.27

Studies28 undertaken of the Australian aluminium industry report a variation between Australian plants of 30 percent. These studies showed there were large fixed 'energy overheads' while the basic process was fairly efficient. Strategies such as optimisation of plant layout, pipe and tank insulation, heat recovery, improved grinding efficiency, efficient anode baking or switching to inert anodes and so on offer potential for efficiency improvement over the long term.

Within smelters, a number of developments offer significant potential for energy savings, including:

- **Improved smelter fume systems**: The power requirement for the fume treatment is determined largely by the choice of technology and factors such as the filter bag area and the pressure drop across the bags as well as fan and motor efficiency and flow resistance. There are likely to be opportunities at some smelters to retrofit high energy efficiency drive systems to fans and to optimise the design of fume transport and control equipment. For instance, Tomago fitted high efficiency fan drives under the NSW GGAS scheme.

- **Improved compressed air systems**: Opportunities to improve energy efficiency exist in the smelting sub-sector in the same way they do in the refining sub-sector.

- **Inert anodes to replace carbon anodes**: Inert anodes reduce the significant amount of energy used to bake carbon anodes and may offer some process control benefits.

- **Heat recovery**: Since pot lines run at close to 1,000°C, there is a large amount of heat available, and the US Department of Energy has provided funding for Alcoa to develop heat exchangers that can cope with the fumes in the waste heat stream. Currently plants are not designed for effective heat recovery, which could provide heat for co-located industries and/or a cogeneration plant (which could sell power into the local grid more profitably than providing it for use within the plant, where it competes with low-priced electricity). Similarly, selling waste heat to co-located industries may be more profitable than using it on-site as it can be sold for a higher price than could be saved through offsetting any internal use.

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28 Ibid.
- Other miscellaneous improvements to fans, lighting, control systems: Overall, savings of 30-40 percent seem feasible over a period of time within smelters, but dematerialisation, recycling and switching to lower energy materials at the point of consumption will drive much larger savings in the long term.

Semi-Fabrication

This part of the industry uses relatively little energy. Opportunities for energy efficiency improvement identified in the semi-fabrication sub-sector include:

- Die oven management (extrusion only).
- Heat treatment - improvements in heat recovery and process optimisation.
- Automated process control.
- Variable speed drives - an opportunity may exist for the use of variable speed drives for presses and in rolling mills.
- Compressed air and lighting - similar opportunities exist in the semi-fabrication sub-sector for improving compressed air lighting systems as in the refining and smelting sub-sectors.
- Ingot heating.

Capture of Downstream Energy Savings through Weight Reduction and Enhancing Recovery and Recyclability

The CSIRO Light Metals Flagship is undertaking research to address the barriers to uptake of increasing aluminium content of car bodies to reduce their weight, and consequently reduce fuel consumption and greenhouse emissions. Vehicle weight reduction is one of the main approaches in the bid to reduce fuel consumption and greenhouse emissions. According to CSIRO, “A weight reduction of ten per cent can increase fuel economy by six to eight per cent. Substituting aluminium for steel in a car body can reduce its weight by 50 per cent and allow savings of approximately 3 000 litres of fuel and 20 kg of CO2 over the lifetime of an average car.”

Another way to significantly reduce greenhouse emissions is by recycling levels. Progress is being made in Australia on this but more could be done. John Marlay, Australian CEO of Alumina stated that, ‘In 2007 the world will consume about 36 million tonnes of aluminium. One-third of that consumption is actually from recycled aluminium requiring 95 per cent less energy than the first time that it was manufactured as primary metal. Over 60 per cent of the aluminium ever produced in the world over the last 80 years is still in use. In construction materials you are getting close to 100 per cent recycling. In the automotive sector, it is 90 per cent recycling, and in packaging, depending on the particular economy, it is between 50 and 60 per cent.’

The Steel Industry

Since the end of World War II, the steel industry has reduced its energy intensity (energy use per shipped ton) by 60 percent, resulting from several key technological innovations. There is a significant list of emerging opportunities that will allow the steel industry to achieve even further

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greenhouse gas emission reductions in the coming decades (see Table 5.1.1), and international collaborations, like the Asia Pacific Partnership on Clean Development and Climate, are working hard on reducing greenhouse gas emissions in this sector. The International Steel Industry Institute study suggests the future may bring energy consumption figures of 12 GJ/t of steel, a saving of a further 60 percent from current values.

**Energy Efficiency Opportunities**

The basic process of making steel has several phases to it. The Steel University\(^{31}\) has created an online technical manual outlining these processes in detail, and at each stage of the process there are energy efficiency opportunities. These are also covered in detail by Martin\(^{32} et\ al^{33}\) and Stubbles,\(^{34}\) in their papers on this sector. Such a detailed analysis is beyond the scope of this project hence readers are referred to these two authors papers for a detailed overview of the wide range of energy efficient opportunities in the steel making sector.

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Table 5.1.1: Overview of a Selection of Energy Efficiency Opportunities in the Steel Sector

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<th>Current Production Technologies</th>
<th>Description</th>
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<tr>
<td><strong>Co-generation</strong></td>
<td>In the steel industry, most cogeneration operations incorporate conventional systems such as steam boilers and steam turbines. However, there are now specially adapted turbines which can burn low-calorific-value off-gases such as coke oven gas, blast furnace gas, and basic oxygen furnace gas, which are produced in significant quantities in integrated steel plants. While electric arc furnaces (EAF) typically use mostly electricity, co-location of an EAF with other industries that require heat means a shared cogeneration facility can be used.</td>
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<tr>
<td><strong>Advanced and high efficiency electricity generation technology</strong></td>
<td>Combined cycle gas turbine (CCGT) can be used to self-generate some of the electricity used in the steel and iron industries.</td>
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<tr>
<td><strong>Coke dry quenching</strong></td>
<td>To recover the heat losses in coke-making to generate electricity.</td>
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<tr>
<td><strong>Pulverized coal injection (PCI) in blast furnaces</strong></td>
<td>Since the late 1980s this technology has become more and more widely used. It allows the coke to be directly injected into the blast furnace, thereby reducing the amount of coal used for steel production by a ratio of 1.4:1.</td>
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<tr>
<td><strong>Top gas recovery turbines (TRT)</strong></td>
<td>To recover the top gas from blast furnaces to generate electricity.</td>
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<tr>
<td><strong>Basic oxygen furnace (BOF) gas/ stream recovery systems</strong></td>
<td>To recover the gas and steam from BOFs and to realise a net negative energy use in BOF steel making processes.</td>
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### Emerging Enabling Production Technologies

<table>
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<tr>
<th>Technology</th>
<th>Description</th>
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<tbody>
<tr>
<td>Smelting reduction iron making</td>
<td>The smelting reduction process no longer requires the coke oven or the sinter plant, and can even run on cheap non-coking coals. These innovations reduce both the operational and up-front capital costs of iron production.</td>
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<tr>
<td>Direct reduction iron – making process</td>
<td>Directly Reduced Iron (DRI) production involves directly reducing iron ores to metallic iron without the need for smelting of raw materials in a blast furnace (which is the most energy intensive process in iron production). In this process, reformed natural gas is used to convert iron ore into partially metallised iron granules.</td>
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<tr>
<td>Thin slab and strip casting</td>
<td>Continuous casting in the integrated steelmaking process provides not only improved yields, but also significant savings in energy. It also involves the casting of molten steel directly into slabs, blooms or billets, eliminating the need for ingot manufacture. Continuous casting replaces three far less efficient process operations. These forms of casting replace the conventional hot rolling mill, thereby bypassing the reheating and roughing steps in normal hot rolling mill production sequences. This produces a thin slab at lower cost with maximal use of the thermal energy of molten iron, while also minimising additional fuel and electricity use downstream.</td>
</tr>
</tbody>
</table>

*Source: Stubbles, J. (2001) and Hamilton et al (2002)*

The energy efficiency of the steel industry could increase by 35 percent through adoption of these new technologies, with the potential for a further 70 percent of overall efficiency improvements using emerging technologies over the coming decades.

Changing production technologies are influencing both the mix and quantity of energy used for steel production. For example, the HiSmelt process developed by Rio Tinto and CSIRO is around 20 percent more efficient than conventional steel blast furnaces and can use iron ore fines that were previously considered to be waste. Electric arc furnaces use mainly electricity for steel production: a typical mid 1990s energy requirement was 550 kWh per ton of product, but best practice is now considered to be around 300 kWh (see Figure 5.1.1), with ‘ideal’ performance around 150 kWh.

There is opportunity for the Australian steel industry to make greater use of cogeneration or, alternatively, an electric arc furnace could be co-located with other industry that requires heat, so they could share a cogeneration facility.

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Reducing Waste to Landfill

There is also significant potential to reduce waste to landfill and thus reduce further greenhouse gas emissions. The Qld EPA and the Foundry Industry Environmental Working Group published the Cleaner Production Manual for the Queensland Foundry Industry to help facilitate the increased practice of beneficial reuse in the industry. This has already helped to reduce the quantity of foundry waste that is sent to landfill and is reducing the cost to industry for disposing of this material. The foundry sector in Australia generates over 50,000 tons of foundry by-products, predominantly sand, each year. Around 85 percent of this material is currently sent to landfill. Beneficial reuse could increase to around 70 percent over the next five years. This would reduce the quantity of material going to landfill by 25,000 tons per annum with a potential annual saving of $500,000. The industry has realised that, beyond the potential benefits of beneficial reuse, there is a significant opportunity to reduce waste and improve resource efficiency at source. These practices can reduce waste disposal costs but also offer benefits such as reduced purchasing costs, improved casting quality, increased productivity from improved work conditions.

Finally, the increased recycling of steel and iron can offer further efficiency gains. For example, it takes at least 60 percent less energy to produce steel from scrap than it does from iron ore.

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Furthermore, waste disposal problems are lessened because used steel can be recycled over and over.

**Opportunities for the Australian Steel Industry**

Steel is struggling to maintain market share in many sectors:

- In the car industry, competition from plastics, composites, aluminium and magnesium is replacing steel and cast iron, and forcing steel suppliers to offer ultra-light steel alloys and other products that have higher value but use less steel and energy to produce.
- In packaging, steel has struggled against aluminium and plastics.
- In buildings and infrastructure, recycled steel is increasing its market share, and there are pressures to reduce the amount of steel used - through stronger steel products, replacement of steel reinforcing by fibre reinforced concrete, and improved computerised structural design techniques.
- At the same time, strong investment in infrastructure development, in China and India especially, and recapture of market share through technology improvement in steel product development has helped to generate unprecedented demand for steel globally.

There is a significant trend towards value-added steel products. For example, stainless steel comprises only about 2 percent of world steel production, but generates 10 percent of the industry’s income from value adding. Australian steel producers are increasing profitability by manufacturing specialised products such as coated and pre-painted steel (Colourbond etc.) which capture much more value than the sale of basic steel as a commodity. Stainless steel is well-suited to production from recycled material, and its use avoids the need for further energy-intensive processes such as galvanising or plating.

In addition, there are a number of exciting original Australian innovations that will help the sector to reduce its carbon footprint and make a difference globally.

Consider for instance, Veena Sahajwalla, a researcher with the University of New South Wales, who won the Eureka Prize for Scientific Research in 2005 for demonstrating a method to use waste plastic to make steel. Her work has shown that certain types of plastic can replace up to 30 percent of coal as a source of carbon in the steel-making process. According to Sahajwalla, ‘Up to 30% of the coal in these (steel) furnaces can be replaced with recycled plastic and we are aiming for more. Not only does the plastic replace coal as a carbon source, it also acts as a fuel, reducing the power requirements for the furnace, and the extreme temperatures of steelmaking eliminate pollutants like dioxins. In Australia, we consume more than one million metric tons of plastic each year. Eighty percent is incinerated or becomes landfill. So plastic waste remains a major environmental concern,’ she says. ‘We are currently testing mixtures of waste plastics, and we hope to implement our technology in the steel industry in Australia and the United States within the next two years.’

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The Cement Industry

The Australian cement industry has an annual turnover of more than AUD$1 billion and 2000 employees across regional Australia. The Cement Industry Federation (CIF) represents Australia's major cement companies, which account for 100 percent of integrated clinker and cement supplies in Australia. Greenhouse issues remain a high priority for the cement industry, as the industry produces globally 1.6 billion tons of cement annually - a ‘glue’ which holds together much of our modern global infrastructure. The cement industry employs about 850,000 workers in facilities in 150 countries, and in 2000 had an estimated global annual revenue of US$97 billion and has grown by nearly 4 percent annually over the last decade.

Figure 5.1.2. Cement industry greenhouse gas emissions

Source: Batelle Memorial Institute (2002)\(^{42}\)

Cement production is energy-intensive and, as a result, the industry is responsible for 3 to 5 percent of global CO\(_2\) emissions. The World Business Council for Sustainable Development has identified the cement sector as one of the six industries on which to focus independent research and stakeholder consultations in order to align the industry’s practices and policies with the requirements of sustainability.\(^{43}\) The Asia Pacific Partnership for Clean Development and Climate is also working on this sector and has set up a Cement Taskforce.\(^{44}\)

Cement Production and Greenhouse Gas Emissions

Cement production inherently consumes large amounts of materials and energy, and innovations that could radically reduce the amount of resources used are hampered by existing standards and specifications. The largest portion of GHG emissions from production of cement worldwide (approximately 50 percent) originates from the process reaction that converts limestone to calcium oxide; the primary precursor to cement (CaCO\(_3\) to CaO+CO\(_2\), as discussed earlier). Other cement related GHG emissions come from: fossil fuel combustion at cement manufacturing operations (about 40 percent of the industry’s emission); transport of raw materials (about 5 percent); and combustion of the fossil fuel required to produce the electricity consumed by cement manufacturing operations (about 5 percent).


In cement plants, direct CO₂ emissions result from the following sources:

- calcination of limestone in the raw materials,
- conventional fossil kiln fuels,
- alternative fossil-based kiln fuels,
- biomass kiln fuel and
- non-kiln fuels.

Over 90 percent of in-house energy is used to fire kilns to heat limestone in the calcination process. The remaining energy is in the form of electricity to operate kilns, clinker grinding plants and other equipment. However, since electricity is usually much more expensive than fuel for heat, electricity can comprise a significant component of energy cost, making it an important target for energy efficiency improvement.

**Energy Efficiency Opportunities**

Since the early 1980s, there has been a steady trend away from other sources of energy and towards a heavier reliance on coal and coke in the global cement industry. Shifting to lower greenhouse intense energy sources would cut associated greenhouse gas emissions. One of the best, technically proven approaches for reducing process emissions lies in reducing the amount of clinker in cement. Substituting cement extenders, pozzolanic materials, such as blast furnace slag, fly ash and natural pozzolans for clinker substantially reduces process-related CO₂ emissions. In addition, the dry process is up to two times more efficient than wet cement production.

Further energy efficiency options include:

1. conversion from direct to indirect firing,
2. improved recovery from coolers, and
3. installation of roller presses, vertical mills and high efficiency separators.
4. shifting from electric motors to gas engines (with heat recovered for process use) for grinding.

Large energy efficiency savings are possible through using new approaches to making cement. Two promising options include Geopolymers and Magnesium Cements.

**Geo-Polymeric Cements**

Geopolymeric cements set quickly, are at least as strong as Portland cements, last longer and are more resistant to fires. They can be cheaply made, based on several types of clay and industrial waste and a few common sedimentary rocks, and they can be formed at much lower temperatures than Portland cement (750 degrees C). The chemical process does not require CO₂ to be produced and hence fabrication of geopolymeric cement produces between 80 and 90 percent less CO₂ than

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Portland Cement.\textsuperscript{46} According to CSIRO, geopolymers can be used for every major purpose for which Portland cement is currently used.\textsuperscript{47}

Through a blend of magnesium oxide and conventional cement, Australian inventor John Harrison of TecEco Pty Ltd. developed ‘eco-cement.’ This new blend of cement incorporates magnesium oxide (magnesia) and wastes to make it environmentally sustainable. Eco-Cement uses a lower heating temperature during manufacturing, so less fossil fuels are used. Wastes such as fly and slags etc. can be included, without incurring problems such as delayed reactions. Eco-Cement also absorbs CO\textsubscript{2} from the atmosphere to set and harden and can be recycled.\textsuperscript{48} To summarise Table 5.1.2 lists the full range of energy efficient opportunities for the cement industry which are discussed in full in Martin, Worrell and Price’s 1999 paper.\textsuperscript{49}

\textbf{Table 5.1.2:} Energy efficient practices and technologies in cement production

<table>
<thead>
<tr>
<th>Raw Materials Preparation</th>
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<tbody>
<tr>
<td>- Efficient transport system</td>
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<tr>
<td>- Raw meal blending systems (dry process)</td>
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<tr>
<td>- Conversion to closed circuit wash mill</td>
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<tr>
<td>- High-efficiency roller mills (dry cement)</td>
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<tr>
<td>- High-efficiency classifiers (dry cement)</td>
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</tbody>
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<table>
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<tr>
<th>Clinker Production (Wet)</th>
<th>Clinker Production (Dry)</th>
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<tr>
<td>- Kiln combustion system improvements</td>
<td></td>
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<tr>
<td>- Kiln shell heat loss reduction</td>
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<tr>
<td>- Use of waste fuels</td>
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<tr>
<td>- Conversion to modern grate cooler</td>
<td></td>
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<tr>
<td>- Optimise grate coolers</td>
<td></td>
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<tr>
<td>- Conversion to pre-heater, pre-calciner kilns</td>
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<tr>
<td>- Conversion to semi-wet kilns</td>
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<tr>
<th>Finish Grinding (applies to wet and dry cement production)</th>
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</thead>
<tbody>
<tr>
<td>- Improved grinding media (ball mills)</td>
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</tbody>
</table>


- High-pressure roller press
- High-efficiency classifiers
- Improve mill internals
- Use of gas engines to replace electric motors

### General Measures

- Preventative maintenance (insulation, compressed air losses, maintenance)
- Reduced kiln dust wastage
- Energy management and process control
- High-efficiency motors and appropriate motor sizing
- Efficient fans with variable speed drivers
- Improved aerodynamic design of air flow paths

### Product Changes

- Blended cements
- Reducing fineness of cement for selected uses
- Geopolymers
- Magnesium based cements

Source: Martin et al (1999)\(^{50}\) with some additions by the authors

### Australian Cement Industry: Achievements to Date

Since 1995, when CIF joined Greenhouse Challenge Plus,\(^{51}\) 1.5 million tons in CO\(_2\)-e emissions has been saved, i.e. 14.4 percent of total emissions. Energy usage and reduction is monitored by the sector using a Greenhouse Energy Management System (GEMS) for each cement company. The establishment of GEMS allows companies to address greenhouse issues by evaluating their position and offering practical solutions to reduce their emissions at both industry and company levels. The major areas where the industry has already made progress are:

1. **Investing in dry process technology**: The dry process eliminates the use of water in the raw feed to the kiln, halving the amount of energy required to convert limestone to clinker (‘cooking’) (see Figure 5.1.3).

2. **Using alternative fuels**: Since the cement manufacturing process is run at high temperature (1450°C) the kilns have the capacity to utilise ‘waste’ products (waste tyres, demolition timbers, waste oil, carbon anode dust, aluminium spent cell liners, solvent based fuels etc.) as a source of fuel for the kilns instead of coal or gas. According to the Cement Industry Federation (CIF), ‘Traditionally in Australia landfill is seen as the cheap and convenient option for disposal. In Europe cement kilns are viewed as an excellent recycling opportunity for waste otherwise disposed of to landfill. Europe’s use of alternative fuels is in the vicinity of 28% substitution for fossil fuels, some plants utilising over 80% of their needs with waste. Australia can also meet this goal with a change of attitude to the use of landfill sites. The current level of use of alternative fuel use in Australia is around 6% and the cement companies are working toward increasing the

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50 Ibid.
usage to 18% over the next decade.\textsuperscript{62} (see Figure 5.1.4) it is important to note that this may not reduce (and may increase) greenhouse gas emissions as material that would have remained inert in landfill releases its CO\textsubscript{2}, and the CO\textsubscript{2} intensity of some waste fuels is higher per unit of energy than the fuel that is displaced.

\textbf{Figure 5.1.3.} Australian clinker capacity by kiln type

\begin{center}
\textit{Source: CIF Annual Survey (2004)}\textsuperscript{53}
\end{center}

\textbf{Figure 5.1.4} Australia Cement Industry, fuel Substitution rates

\begin{center}
\textit{Source: CIF Annual Survey (2004)}\textsuperscript{54}
\end{center}

3. \textit{Investing in smaller technological improvements}: These can and have been made during the shutdown periods that usually occur annually. These improvements include upgrades to fans, installation of high efficiency classifiers on grinding mills, improved burner technology, use of electronic surveillance, and control of the entire manufacturing process.

4. \textit{Investing in new methods of cement production}: Methods such as geo-polymers and magnesium cements.

\textsuperscript{52} Ibid, p 5.
\textsuperscript{54} Ibid, p 6.
5. *Increasing the percentage of cement extenders (blast furnace slag and fly ash. Another way to significantly reduce greenhouse gas emissions is to use blast furnace slag and fly ash to replace a proportion of Portland cement. This approach reduces the embodied energy as they are cementitious and involve much less energy to produce. They reduce greenhouse gas emissions both through reduced energy use and reduction in the quantity of process CO₂ from calcination per ton of final product. Cement extenders are used to some extent by the mainstream cement industry, with an average extender content close to 20 percent being used in Australia in 2005. However, much higher proportions of extenders can be used, up to 60 percent or even 85 percent.*

Optional Reading


   Aluminium Sector


Steel Sector


Cement Sector


Keywords for Online Searching

Aluminium energy efficiency opportunities, Steel energy efficiency opportunities, Cement energy efficiency opportunities.