A review of the Regional Synergy Development in Gladstone

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RESEARCH REPORT

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Executive Summary

The main aim of this case study is to map the progress of regional synergy development in Gladstone industrial area from 2004 to 2012 and identify the potential progress up to 2020. An additional aim is to investigate the barriers and enablers for delivering greater sustainability benefits to the minerals industry in the area through the application of industrial ecology principles.

This case study is built on previous similar research (Gladstone Regional Synergies Project 2004-2007), which was supported by GAIN (Gladstone Industry Area Network), the industry network body at that time.

The potential benefits of this case study for industrial members and the City of Gladstone include:

- Better understanding of the barriers that hinder further development of industrial cooperation in the area, and the analysis of possible actions to mitigate these barriers;
- Understanding the progress in regional resource synergies in comparison with previous similar research (GRSP 2004-2007);
- A summary of the current industrial environmental impact and its potential growth considering new projects in 2012-2020 (Yarwun alumina refinery stage 2, oil shale technology development facility, GPNL nickel refinery, steel plant, LNG projects);
- An investigation of new potential synergies within existing and coming industries.

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1 Introduction

1.1 Aims and expected outcomes from the research

Gladstone is the largest industrial area in Queensland, Australia, which includes a coal power station, two alumina refineries, an aluminium smelter, cement producer, and ammonia nitrate producer.

The first regional resource synergies study in Gladstone was implemented in 2004-2007 as a special research project funded by the Cooperative Research Centre for Sustainable Resource Processing (CSRP) and the Gladstone Area Industry Network (GAIN) industries (Corder, 2008). The main outcomes form this project include the detailed analysis of waste material/energy/water flows in the area (based on 2004 data) (Corder, 2005), the investigation of new possible initiatives for the large and smaller waste streams (Corder, 2006), and the comparison of the synergies in Gladstone with another well known industrial symbiosis example – Kwinana in Western Australia (Bossilkov et al., 2005). In the final report of this research, there was also an attempt to analyse the reasons for the lack of new synergies uptake during the life of the project (Corder, 2008).

The new synergies research in Gladstone aims:

- to analyse in detail the Industrial Ecology barriers in the Gladstone industrial area,
- to update the waste material flows analysis, taking into account the changes within existing industries and expected influence of new industries, and
- to test the new framework developed through the author's PhD research, and its effectiveness for the regional resource synergies studies.

Expected outcomes from the Gladstone case study:

- Better understanding of the barriers that hinder further development of industrial cooperation in the area, with the analysis of possible actions to mitigate these barriers.
- The study of the progress in regional resource synergies in comparison with previous similar research (Gladstone Regional Synergies Project 2004-2007).
- The summary of the current industrial environmental impact and its potential growth considering new projects in 2012-2020 (Yarwun alumina refinery stage 2, oil shale technology development facility, GPNL nickel refinery, steel plant, LNG projects).
- The investigation of new potential synergies within existing and coming industries.

1.2 Research scope

This research mainly targets large industries and solid waste streams in the Gladstone industrial area as the major contributors to environmental impacts in the area. However, for the estimation of future waste streams, emissions and effluents have been also considered along with the solid wastes.

The list of existing industries and stakeholders that are included in this study consists of:

- alumina refineries Queensland Alumina Ltd (QAL) and Rio Tinto Alcan Yarwun (RTA),
- aluminium smelter Boyne Smelters Ltd (BSL),
- NRG Gladstone power station (NRG),
- cement producer Cement Australia Holdings Pty Ltd (CA),
- chemical company Orica Ltd,
- oil shale demonstration plant QER Pty Ltd,
- waste management company JJ Richards,
- Gladstone Industrial Leadership Group (GILG),
- and Gladstone Economic and Industry Development Board (GEIDB)[1].

Other industries and stakeholders, that are not included in this study but also recognised as existing or potential agents for regional resource collaboration in Gladstone, are represented by:

- Gladstone Area Water Board (GAWB),
- Gladstone Ports Corporation,
- waste transfer stations/landfills (Benaraby Landfill and Gladstone Waste Management Centre),
- ice cream sticks manufacturer, a private company Austicks Pty Ltd,
- limestone producer, a private company Frost Enterprises Pty Ltd,
- waste management companies Veolia Environmental Services and Transpacific Industries,
- Gladstone Region Environmental Advisory Network (GREAN).

New emerging and potential industries in Gladstone that have been observed in this report include:

- LNG projects (Queensland Curtis LNG, GLNG, Australian Pacific LNG, etc.),
- oil recycling plant Northern Oil Refineries Pty Ltd,
- Aldoga power station,
- nickel and cobalt metals refinery Gladstone Pacific Nickel Ltd (GPNL),
- iron and steel producer Boulder Steel Ltd.

[1] The GEIDB closed on 30 June 2012. The roles and responsibilities of the GEIDB are being undertaken by the Department of State Development, Infrastructure and Planning.

2 Existing Industries Overview

2.1 QER Pty Ltd (Queensland Energy Resources)

QER Pty Ltd holds mining rights to develop several large oil shale deposits across Australia including the Stuart oil shale deposit, which is about 15km to the north of Gladstone and just across the road with the Cement Australia facilities.

A small-scale oil shale plant with the new Paraho II™ technology was launched in 2011, at a cost of more than A$100 million. The production level of the new demonstration plant is about 37-40 barrels of synthetic crude oil a day by processing approximately 60 tonnes of dry oil shale feed. The final products, after oil upgrading, are diesel, aviation fuel and light fuel oil (QER, 2011). The main purpose of the plant is to demonstrate the efficiency and safety of the improved technology to the shareholders, government and community before commencing the full-scale operation in the next 5 to 10 years.

2.1.1 By-products and wastes

The main by-product and waste streams of the oil shale processing are the sour gas, containing the mixture of hydrogen sulphide and ammonia, overburden from mining operations, and spent shale from the processing plant (~80% of the mass fed into the process). Other wastes are generated in relatively small quantities and include spent catalyst, recycling and general wastes.

With a small-scale operation currently, most wastes/by-products have no feasible reuse option. The sour gas is incinerated, while spent shale goes back to the mine site for use as backfill.

The information from the QER's official website (www.qer.com.au) indicates that, in the case of the success of the demonstration plant, the company plans to develop the full-scale project in two stages:

- stage 1 (plant 1) with the production of 3,000 barrels of synthetic crude oil per day (multiplication factor of 75 if compared with the capacity of the demonstration plant);
- and stage 2 (plant 2) with the production of 20,000 barrels of crude oil per day (factor of 500).

However, no details for the timeline of this project development are available currently.

2.1.2 Previously described opportunities and synergies

Several potential synergies were suggested for the full-scale oil shale plant in the previous report (Corder, 2005), including the recovery of ammonia, waste heat reuse and the reuse of spent shale for cement production. These synergies and their current status are summarised in the table below.

Table 2.1 QER – summary of synergy opportunities indicated in previous research

Suggested/existing synergy	From	To	Current status	Notes
1. Recovery of ammonia from the sour gas	QER	Orica/ GPNL	Delayed (full-scale)	Considered as an option for the full-scale operation. Will need additional feasibility study
2. The use of waste heat (500°C) to pre-heat shale, generate steam and electricity	-	-	Delayed (full-scale)	Considered as an option for the full-scale operation. Will need additional feasibility study
3. To feed old tyres to the process to extract their oils and reduce oil shale consumption	Different suppliers	QER	Considered	Further investigation and feasibility study are expected
4. The use of red mud as a backfill for the mine	QAL/RTA	QER	Rejected	No need. The amount of waste materials (spent shale and overburden) will be enough to backfill the mine. The red mud maybe considered as a part of the cover material mix for land rehab
5. To use processed shale as a cement additive	QER	CA	N/A	Unlikely to use as a cement additive due to the high carbon content in the spent shale, but maybe suitable for clinker production (see Section 2.1.3)

N/A – the data is not available or there were no further investigation.

The most valuable synergy suggested in the previous report is ammonia recovery. For a full-scale plant (stage 2) the production of ammonia is estimated to be between 50-100 ktpa. This would cover up to 30% of Orica's ammonia consumption for the ammonium nitrate production.

Another interesting synergy is reusing old tyres in the processing of oil shale. This may result in raw shale and energy savings, and higher oil output. The oil yield in the pyrolysis of car and track tyres is relatively high – around 50 wt% (Ucar et al., 2005). This, however, has to be confirmed for the QER's technology. Old tyres can be pre-treated in several ways from large shred tyre chips (that was used as an alternative fuel at Cement Australia) to the rubber granules and powder obtained through the old tyres recycling process with steel and textile removal (van Beukering and Janssen, 2001). Additionally, the use of tyres in oil shale processing may result in slightly higher hydrogen sulphide yield and higher residual carbon content in spent shale.

2.1.3 Other potential synergies

Other opportunities are related to the main by-product and waste streams: spent shale and sour gas.

Spent shale is commonly used as a refill material for existing mines (Gwyn, 2001, Winter, 2001). QER also has initiated a research project within the Centre for Mine Land Rehabilitation (at SMI, The University of

Queensland) for possible mixture of spent shale with other waste materials (overburden and top soil at the mine site, red mud and fly ash from QAL) for rehabilitation purposes.

Spent shale also contains significant residual carbon and can be used as a fuel material (Al-Otoom, 2006). QER plans to investigate the feasibility of electricity/steam cogeneration for a full-scale operation.

The literature analysis has revealed several examples of oil shale/ spent oil shale/ oil shale ash reuse for construction materials (Al-Otoom, 2006, Purga, 2008, Winter, 2001, Francu et al., 2007). The most promising option is the reuse of spent shale (and in some cases oil shale with low oil yield) for clinker production where it can substitute coal and raw meals (for silica, alumina, lime and iron oxides content) (Purga, 2008). There are only a few examples of this synergy in the world (Holcim cement plant in Dotternhausen, Germany, Pan-Malaysia Cement, Kunda Nordic Cement in Kunda, Estonia, and new spent oil shale based cement plant in Slantsy, Russia), but this seems to be the best solution. The limiting factors for this reuse option are usually the distance between oil shale plants and cement producers, as well as the fact that the amount of generated spent shale may be significantly higher than cement producers' capacities to process it (Purga, 2008).

Figure 2.1 Spent oil shale (QER, Gladstone)

A Jordanian study suggested that spent shale (from Jordanian deposits) can substitute up to 16% of raw meals for a typical Portland cement clinker without affecting its main properties, with additional benefit of reducing the required clinkering temperature to around 1300°C instead of the typical 1450-1500°C (Al-Otoom, 2006). The information on new 1.86 Mtpa cement plant in Slantsy, Russia, launched at the end of 2010, says that the addition of spent shale can be up to 50% of a raw mixture (it is worth noting that this plant reuses previously accumulated oil shale processing wastes, estimated at around 100 million tonnes) (LSR, 2010).

Currently, QER generates about 15-20 ktpa of spent shale, with its potential growth up to several million tonnes per year for a full-scale operation.

The sour gas from oil shale processing contains a mix of ammonia and hydrogen sulphide. The extraction of ammonia for use at Orica was discussed above. The sulphur (and hydrogen) utilisation is also an important potential synergy. The incineration of sour gas for a full-scale operation would mean significant costs for the treatment of sulphur dioxide emissions. There are several sulphur based chemicals that can be produced from hydrogen sulphide for QER conditions – elemental sulphur (S), sulphuric acid (H_2SO_4), ammonium sulphate ($(NH_4)_2SO_4$), and gypsum ($2H_2O{\cdot}CaSO_4$) - which could reduce or negate the cost of sour gas treatment.

Elemental sulphur is a marketable product preferably used for the production of sulphuric acid which has only limited use inside the Gladstone industrial area. Gypsum, on the contrary, can be mostly consumed within the area for cement production, but it is a low value product and may hardly cover the costs for its processing. Elemental sulphur can also be used for land rehabilitation at the mine site and around Gladstone to decrease soil alkalinity.

Ammonium sulphate is preferably used as a fertiliser, especially on alkaline soils. Its production at QER would utilise both chemicals (ammonia and sulphur) at the same time. However, this is well outside QER's main business – oil production – and a separate plant and business operator could be the better choice in the case of this fertiliser production.

Table 2.2 QER – summary of other potential synergies

Suggested/existing synergy	From	To	Current status	Notes
1. Spent shale as waste fuel for steam/electricity generation	QER	QER	Considered (full-scale)	Will need additional tests and feasibility study
2. Sulphur based chemicals manufacture (utilisation of hydrogen sulphide): - elemental sulphur, - sulphuric acid, - ammonium sulphate, - gypsum	QER	CA/Orica/ QAL/RTA/ NRG/BSL	Considered (full-scale)	Will need additional feasibility study. The manufacture of specific chemicals may depend on its feasibility and market conditions
3. Oil shale (oil shale with low oil yield) for clinker production (coal and raw meals substitute)	QER	CA	N/A	-
4. Spent shale for clinker production (coal and raw meals substitute)	QER	CA	N/A	Needs special investigation and trials
5. Shale ash (from oil shale/ spent shale burning)	QER	CA	N/A	Will need additional tests and feasibility study. Shale ash has similar properties to coal fly ash, and low transportation costs to deliver it from QER to CA

6. Spent shale/ shale ash/ waste rock as road base filling/aggregate	QER	different customers	N/A	Needs special investigation and trials
7. Hydrogen sulphide	QER	GPNL	N/A	Will need additional feasibility study. The GPNL project is currently delayed
8. Ammonia	QER	GPNL	N/A	

A potential worthwhile opportunity for the QER's sulphur and ammonia utilisation relates to the Gladstone Pacific Nickel Limited (GPNL), if this project proceeds. The existing plan for GPNL includes on-site sulphuric acid and hydrogen sulphide plants, with an external supply of sulphur imported from overseas. Ammonia is another important chemical for the nickel plant, which is planned to be sourced from outside the region. The final by-product of the nickel ore processing is ammonium sulphate. The estimated needs for GPNL (stage 2, full-scale): 95 ktpa of ammonia, and 1.6 Mtpa of sulphur (GPNL, 2007, GPNL, 2008).

The most valuable possible synergy between QER and GPNL is the direct supply of hydrogen sulphide, which is used at the mixed sulphide precipitation stage to recover nickel and cobalt. This would save the natural gas consumption at GPNL (for the production of hydrogen gas to synthesise H_2S), and decrease the capital and operating costs for sour gas treatment at QER (without sulphur production).

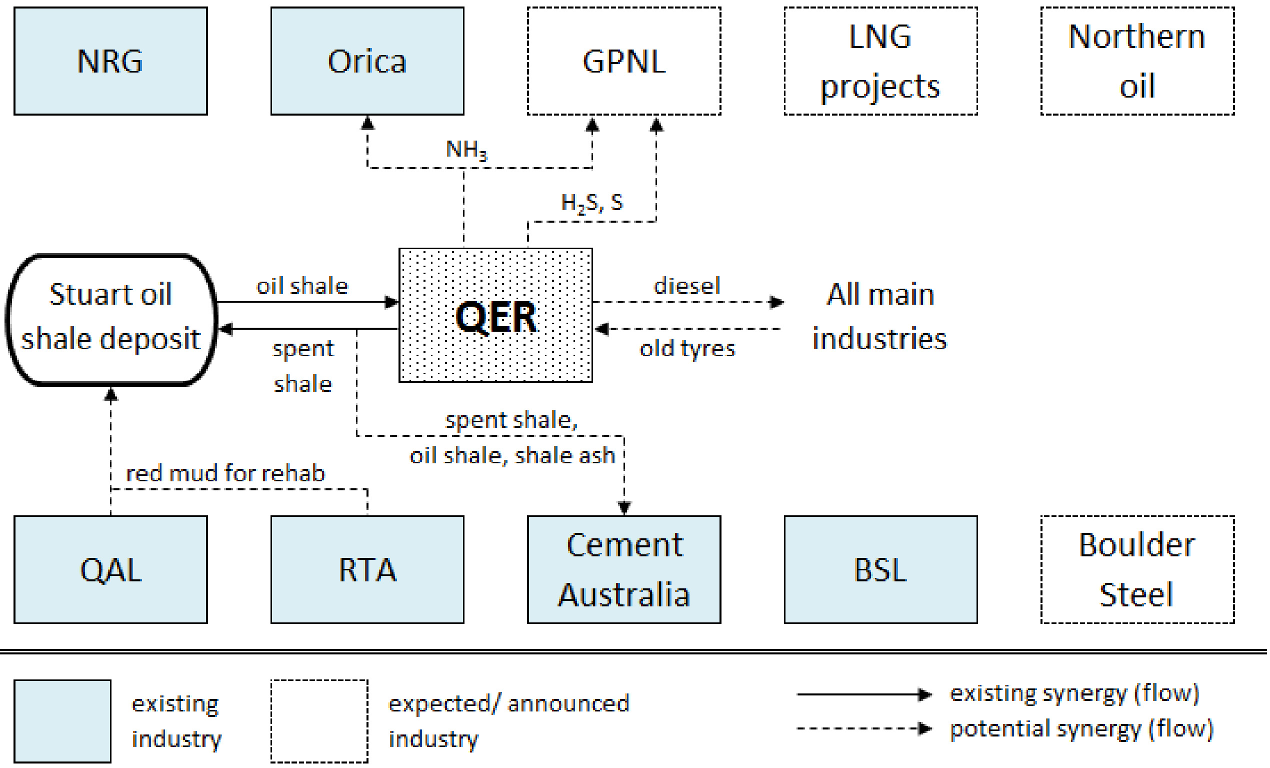


Figure 2.2 QER: main potential synergies within Gladstone industrial area

2.2 Cement Australia Holdings Pty Ltd – Gladstone

Cement Australia's Gladstone facility at Fisherman's Landing is the largest cement plant in Australia, with a production capacity of over 1.7 million tonnes of cement per annum. The raw materials, such as limestone and clay, are supplied from the East End quarry at Mt Larcom, 24 km from Gladstone, Queensland's largest limestone mine. The production of lime is also an important part of the operation; produced lime is supplied to different customers around the region.

2.2.1 By-products and wastes

Cement production has a low level of solid waste generation. However carbon dioxide emissions are significant and vary from 0.65 to 0.92 t of CO_2 per tonne of cement (OECD/IEA, 2007), depending on the level of alternative fuels and raw materials (AFR) reuse and overall energy efficiency.

The main waste materials of cement and lime processing include lime kiln dust (partly reused on site) and off spec lime that are suitable to use in land rehabilitation, primarily as an additive to acidic soils.

The variety and volume of AFR utilisation at Cement Australia in Gladstone is still at relatively low level – 3.4 wt% overall in 2011 (and around 2.5 wt% in 2004). Accordingly, it means a higher carbon footprint per tonne of product for the Gladstone plant.[2]

The most valuable AFR synergies in the Gladstone area (Table 2.3) are:

- **spent cell linings (calcined ash)** as an alternative fuel, delivered from BSL at their own costs and with additional charge for its utilisation in clinker production. Alternatively, this waste material is stored at BSL for further reuse or disposal;
- and **fly ash** as a cement additive, delivered from NRG coal power station. The addition of fly ash to cement was around 3 wt% in 2011, calculated as an average of all types of produced cement. This is significantly lower than the suggested utilisation rate in the literature (Kumar et al., 2006), and is probably due to the small quantities of blended cements in the overall production (the information provided at the official Cement Australia website says that the addition of fly ash can be up to 50% for blended cements). However, fly ash may be also used directly for concrete production, and the amount of fly ash collected by Pozzolanic Enterprises (Cement Australia subsidiary) from NRG is several times higher than those used as a cement additive at Fisherman's Landing.

[2] The cement producers usually estimate the carbon footprint per tonne of sold cementitious materials, which also includes fly ash and other substitutes sold directly to customers for concrete production and other purposes. See, for example, TAYLOR, M., TAM, C. & GIELEN, D. 2006. Energy efficiency and CO_2 emissions from the global cement industry. International Energy Agency.

Table 2.3 Cement Australia – the use of alternative fuels and raw materials

Alternative fuel/material	2004*	2011	Notes
Clinker production			
1. Calcined ash (SCL), t	-	11,604	Delivered from BSL
2. Solvents, kL	15	2,542	Delivered by Geocycle from outside of QLD
Cement production			
3. Fly ash, t	18,661	37,305	Delivered from NRG
4. Copper slag, t	45,000	31,534	Delivered from Japan
5. Steel slag, t		-	-
TOTAL	**63,676**	**82,985**	

** 2004 data obtained from (Corder, 2005) report, and, most probably, were calculated as an approximation for 2003-2004 by the Cement Australia representative.*

2.2.2 Previously described opportunities and synergies

Out of the nine main previously reported opportunities for Cement Australia (Corder, 2005):

- four are in use (fly ash, SLC, solvent-based fuels and lime kiln dust recycling),
- one is considered for the future (lime dust/ off spec lime as a soil additive),
- two are rejected (tyres, and boxes, bags and oily wastes reuse as alternative fuel),
- and the status for the last two (spent shale and met coke dust) is unknown (Table 2.4).

Table 2.4 Cement Australia – summary of synergy opportunities indicated in previous research

Suggested/existing synergy	From	To	Current status	Notes
1. Fly ash as a cement additive	NRG	CA	In use	-
2. Alternative fuel materials (AFR): solvent-based fuels	Geocycle	CA	In use	Geocycle Pty Ltd is a part of the Cement Australia Group
3. Spent cell linings (SCL) (calcined ash) as a fuel material	BSL	CA	Implemen-ted	BSL covers the costs for SLC pre-drying in calciner, milling, transportation to Cement Australia, and also pays an extra fee for its reuse in clinker kiln
4. Lime dust: recycling in clinker production	CA	CA	Implemen-ted	Most of lime kiln dust is reused in clinker production, the reminder is disposed
5. Lime dust/ off specifica-tion lime as a soil additive	CA	Different customers	Considered	Potential reuse in soil remedia-tion on Curtis Island (construction work for new LNG plants)
6. AFR: tyres	Different suppliers	CA	Rejected	Cause problems in kilns; handling issues have to be resolved first
7. AFR: boxes, bags, oily wastes	Orica/BSL/ QAL/RTA	CA	Rejected	Cause problems in kilns; handling issues have to be resolved first
8. AFR: met coke dust and fines	BSL	CA	Rejected	Possibly, due to the low calorific value

9. Processed shale as a cement additive	QER	CA	N/A	Unlikely to use as a cement additive due to the high carbon content in the spent shale, but maybe suitable for clinker production (see Section 2.1.3)

2.2.3 Other potential synergies

Several other examples of potential synergies are addressed in the literature for cement production that could be applied in the Gladstone area. These include the continuing interest in red mud, high-carbon fly ash, construction and demolition waste utilisation in clinker production, and waste heat reuse for electricity generation.

The reuse of high-carbon fly ash as a 3% addition to clinker raw mix has demonstrated a 2.6% reduction in the fuel consumption with slight increases in CO, NO_x and SO_x emissions for an American case study (Bhatty et al., 2003). Most publications and research around red mud utilisation define the feasible rate for the red mud reuse in cement production from 1 to 5 wt% of the raw mix (Tsakiridis et al., 2004, Pontikes and Angelopoulos, 2012). The substitute of Portland cement raw meal by the recycled concrete and masonry aggregates can be up to 100%, without affecting the characteristics of the modified raw meals (Galbenis and Tsimas, 2006).

Despite the fact that cement industry is energy intensive and a significant part of input energy is lost with waste heat streams, the co-generation of electricity and steam is not widely used (Rasul et al., 2005, Ali et al., 2011, Madlool et al., 2012). The feasibility of waste heat reuse systems is site specific, and just a few successful cases have been reported in the literature (Khurana et al., 2002, Wang et al., 2009, Madlool et al., 2011, Benhelal et al., 2012, Sharma, 2007).

The realisation of the Boulder steel project (5 Mtpa of iron production at stage 2) can also bring new synergy opportunities for Cement Australia. Such waste materials as granulated blast furnace slag and basic oxygen furnace process slag are well known as additives to cement and road base materials. In fact, these have previously been used as alternative raw materials in the Cement Australia – refer to Table 2.3. The amount of slag generation is about 10-15% of iron production (Zhang et al., 2011). In turn, the future Boulder steel plant, as well as the GPNL nickel plant, will need significant quantities of limestone and lime for ore processing, which could potentially be supplied by Cement Australia.

The opportunities to reuse QER's spent shale, raw oil shale and shale ash in clinker production are discussed in Section 2.1.3.

The summary of the potential synergies discussed above is provided in the table below. All existing and potential synergies for Cement Australia are also illustrated in Figure 2.3.

Table 2.5 Cement Australia – summary of other potential synergies

Suggested/existing synergy	From	To	Current status	Notes
1. Oil shale (oil shale with low oil yield) for clinker production (coal and raw meals substitute)	QER	CA	N/A	Potential problems may relate to the high organic content in raw oil shale
2. Spent shale for clinker production (coal and raw meals substitute)	QER	CA	N/A	Needs special investigation and trials
3. Shale ash (from oil shale/ spent shale burning)	QER	CA	N/A	Will need additional tests and feasibility study. Shale ash has similar properties to coal fly ash, and low transportation costs to deliver it from QER to CA
4. Fly ash with high residual carbon content for clinker production (coal and raw meals substitute)	NRG	CA	N/A	This fly ash is currently rejected as not suitable to use as a cement additive, but may be added to the raw mixture (clinker production)
5. Red mud for clinker production (raw meals substitute)	QAL/ RTA	CA	N/A	The reuse of red mud for this purpose is limited to 1-5 wt% of the raw mixture
6. Waste heat reuse for electricity generation	CA	CA	N/A	-
7. Granulated blast furnace slag	Boulder steel	CA	N/A	The Boulder Steel project is currently delayed
8. Basic oxygen furnace steel slag (BOFS)	Boulder steel	CA	N/A	BOFS is preferably used as an aggregate material, but maybe also suitable for clinker/cement production

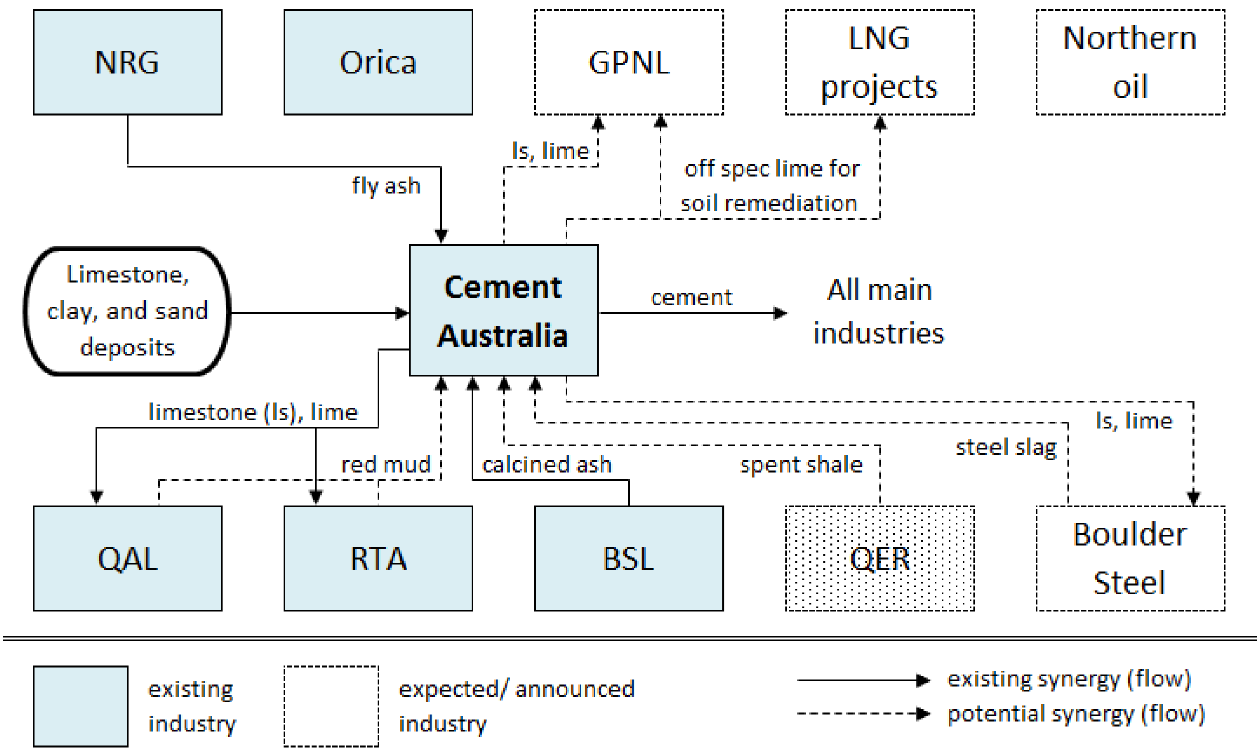


Figure 2.3 Cement Australia: existing and potential synergies within Gladstone industrial area

2.3 Boyne Smelters Ltd

Boyne Smelters Ltd (BSL) is Australia's largest aluminium smelter with annual production of 560 Mtpa (2011). The smelter is situated on Boyne Island about 20 kilometres south of Gladstone. The main suppliers for the plant are QAL (alumina) and NRG (electricity).

2.3.1 By-products and wastes

A significant part of the waste and by-products from BSL has a secondary reuse option; the overall level of recycling is about 80 wt%. The main waste streams include:

- spent cell linings (calcined ash) – supplied as a waste fuel material to Cement Australia,
- aluminium scrap, dross and prills – recycled on-site for aluminium metal production,
- burn-off butts – recycled on-site for new carbon anodes,
- scrap metal – recycled off-site,
- wood and timber – mostly chipped and reused at QAL for weeds suppression,
- refractory bricks – stockpiled for possible future reuse,
- met coke fines and dust – disposed,
- construction waste (mainly concrete) – disposed,
- shotblaster dust – disposed.

2.3.2 Previously described opportunities and synergies

Six main synergies and synergy opportunities were reported for BSL before (Corder, 2005), out of these:

- two are in use (burn-off butts recycling into anodes, and spent cell linings as an alternative fuel),
- one is replaced (aluminium scrap is recycled onsite),
- one is no longer is done as it was running at a loss (production of caustic soda from spent cell linings),
- one is rejected (met coke dust and fines as a fuel material due to its low calorific value),
- and one has not found any application yet (refractory bricks).

The production of caustic soda from spent cell linings (SCL) at BSL was considered as one of the most environmentally beneficial synergies in the Gladstone area earlier (Corder, 2005). Nevertheless, due to unfavourable economics – significant costs for SCL processing and no revenue for its supply (caustic soda was supplied to QAL at no charge), this synergy was cancelled. Most of the SLC is currently reused as an alternative fuel at Cement Australia (BSL covers the pre-processing and transportation costs, and also pays an additional fee for SLC utilisation in clinker kiln).

A short summary of the above mentioned synergies is provided in the table below.

Table 2.6 Boyne Smelters – summary of synergy opportunities indicated in previous research

Suggested/existing synergy	From	To	Current status	Notes
1. Recycling of aluminium scrap, dross and prills	BSL	Smorgon-Steel	Replaced	BSL's metal reclamation facility started in 2010. All aluminium scrap, dross and prills are recycled now onsite
2. Burn-off butts are recycled and combined with petroleum coke and liquid pitch to produce new carbon anodes	BSL	BSL	In use	-
3. Spent cell linings (SCL) as a fuel material	BSL	CA	Implemen-ted	BSL covers the costs for SLC pre-drying in calciner, milling, transportation to Cement Australia, and also pays an extra fee for its reuse in clinker kiln
4. The production of caustic soda (low concentration) from SCL	BSL	QAL/QER	Cancelled	Not feasible in comparison with direct disposal and-or reuse as an alternative fuel at CA
5. Met coke dust and fines as a fuel material	BSL	CA/NRG	Rejected	Could be also made into briquettes for fuel
6. Reuse of refractory bricks as a construction material	BSL	Different customers	N/A	Stockpiled for possible reuse

2.3.3 Other potential synergies

There are not many synergy opportunities for BSL with any of the new possible industries to the Gladstone area. However, one of potential connection might be with Boulder Steel: the utilisation of met coke fines as a fuel material in the blast furnace, which is similar to the dust waste recycling at a steel plant (see, for example, Senk et al., 2006, Çamci et al., 2002).

The success of BSL's metal reclamation facility, started in 2010, opens the possibility to recycle different aluminium scrap sourced from outside the smelter. This could have a significant benefit for BSL taking into account high energy requirements for a primary aluminium metal production and the introduction of carbon tax in Australia.

The production of wood chips for mulch has been also included in the summary of other potential synergies in Table 2.7, as it was not reported before. All existing and potential synergies for BSL are also illustrated in Figure 2.4.

Table 2.7 Boyne Smelters – summary of other potential synergies

Suggested/existing synergy	From	To	Current status	Notes
1. Met coke dust and fines as a fuel material	BSL	Boulder steel	N/A	Different types of dust are typically can be reused at a steel plant for iron recovery and as fuel substitutes. The Boulder Steel project is currently delayed
2. Aluminium scrap recycling (sourced outside BSL)	Different suppliers	BSL	N/A	-
3. Wood chips production from waste wood and timber (used for mulch)	BSL	QAL	In use	Wood chips are reused for weeds suppression

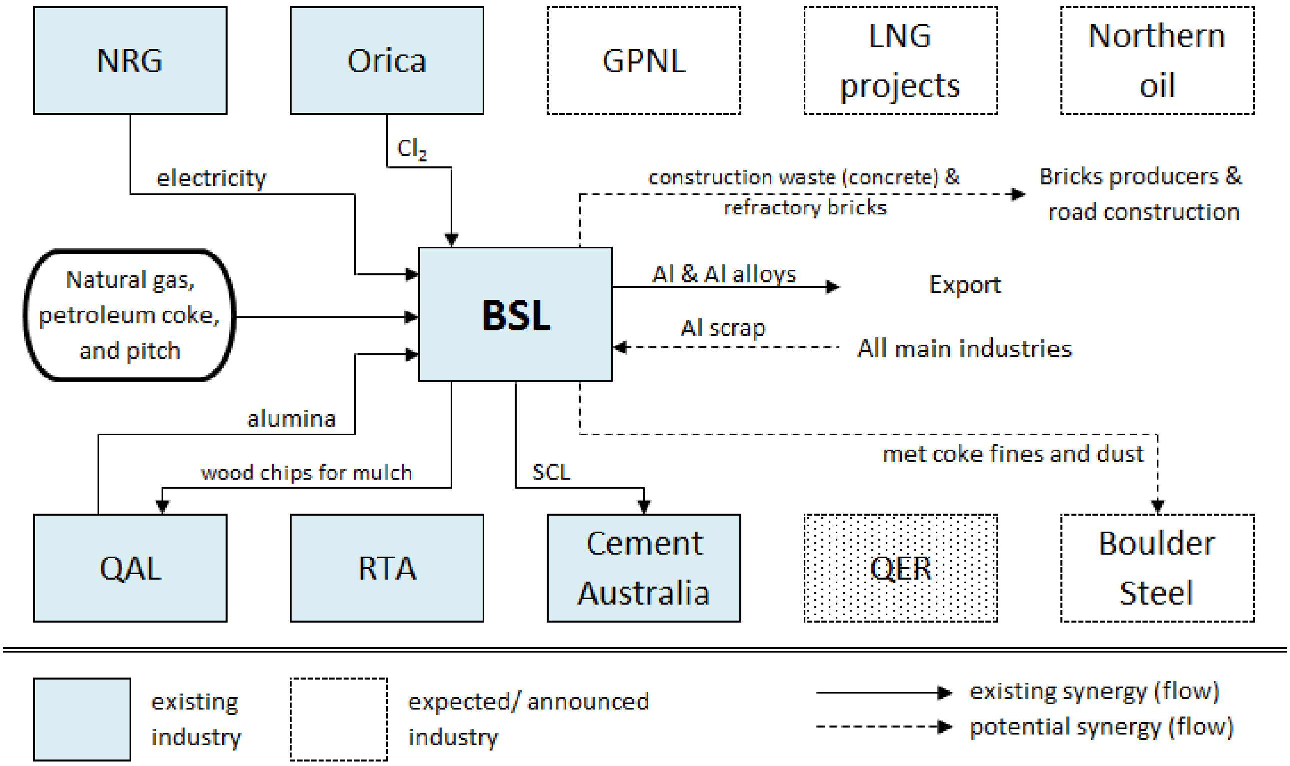


Figure 2.4 BSL: existing and potential synergies within Gladstone industrial area

2.4 Orica Ltd – Gladstone

Orica Ltd is a large producer of ammonium nitrate – an explosive for mining operations (590 ktpa), sodium cyanide – predominantly used for gold extraction (95 ktpa), and chlorine (9 ktpa). The plant is situated about 7 km north-west of Gladstone, and 2 km east of the Rio-Tinto Alcan alumina refinery.

2.4.1 By-products and wastes

Orica is continuously improving its operational efficiency in line with its Corporate zero waste policy, and as a result the amount of generated solid wastes is at a fairly low level. Main by-products and waste include:

- fertiliser solution (NH_4NO_3) – seasonally supplied as a nitrogen fertiliser,
- wooden waste – delivered to a local landfill for further reuse as a mulch,
- containers – mostly reused,
- waste sulphuric acid – partly reused onsite, while the remainder is transported to the Orica's facility in Port Kembla (NSW) for recycling,
- filter cake (Ca and Mg salts, fibre) – as regulated waste, transported to a special landfill near Brisbane,
- scrap metal – recycled off-site,
- ammoniated water.

2.4.2 Previously described opportunities and synergies

The previous report includes six synergy opportunities for Orica (Corder, 2005), their current status consists of (Table 2.8):

- one synergy is in use (fertiliser solution),
- three are rejected (waste as an alternative fuel, filter cake for land reclamation, collective purchasing scheme for commodities),
- and two synergies are delayed, as not feasible under current economic conditions (waste water reuse, and waste heat recovery).

Table 2.8 Orica – summary of synergy opportunities indicated in previous research

Suggested/existing synergy	From	To	Current status	Notes
1. Fertiliser solution (ammonium nitrate)	Orica	Agricultural companies	In use	The demand is seasonal
2. Storage boxes, waste oils and greases, bags, poly-propylene wrapping as an alternative fuel	Orica	CA	Rejected	No detailed technical explanation is available; handling issues have to be resolved first
3. Brine filter cake (Ca and Mg salts, fibre) for land reclamation	Orica	CQPA	Rejected	Filter cakes are regulated waste, transported to a special landfill near Brisbane

4. Collective purchasing scheme for commodities, such as caustic soda	Orica/QAL/ RTA	-	Rejected	Commercial reasoning
5. Water reuse from site/ waste transfer facility	WTP	Orica	Delayed	Potential project, being investigated
6. Waste heat recovery (electricity and steam generation)	Orica	Orica, et al.	Delayed	Potential project, not feasible currently

2.4.3 Other potential synergies

The realisation of QER and GPNL projects in Gladstone may bring some new synergies for Orica, notably the ammonia supply from QER (see for details Section 2.1.3), sulphuric acid supply, and the recycling of spent sulphuric acid at GPNL's (or QER's) plant.

The summary of other potential synergies is provided in the Table 2.9. All existing and potential synergies for Orica are also illustrated in Figure 2.5.

Table 2.9 Orica – summary of other potential synergies

Suggested/existing synergy	From	To	Current status	Notes
1. Ammonia supply	QER	Orica	N/A	The QER's full-scale project is delayed
2. Sulphuric acid supply	GPNL/ QER	Orica	N/A	The GPNL project is delayed
3. Spent sulphuric acid recycling	Orica	GPNL/ QER	N/A	Currently recycled at Orica's facility in Port Kembla (NSW)

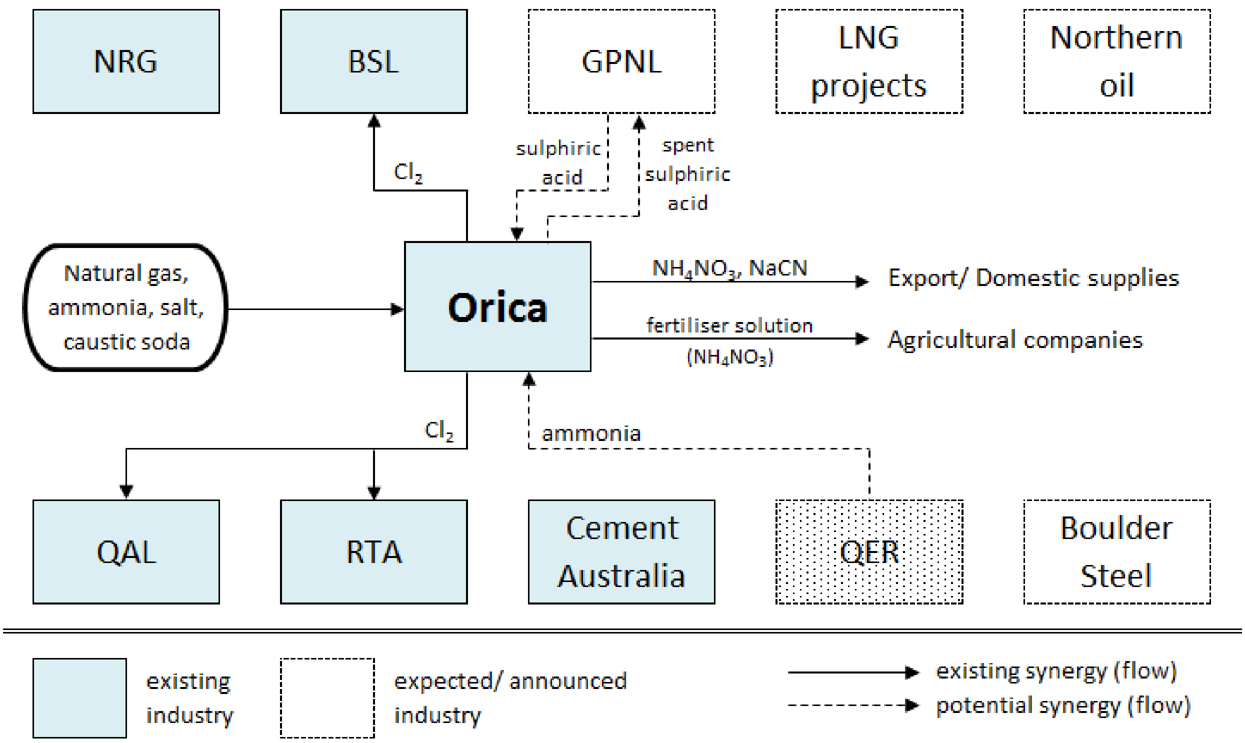


Figure 2.5 Orica: existing and potential synergies within Gladstone industrial area

2.5 NRG Gladstone power station

NRG is the largest single coal fired station in Queensland with total generating capacity of 1680 MW. The plant is situated just a few kilometres from the centre of Gladstone. It is operated by NRG Gladstone Operating Services on behalf of Joint Venture participants of which Rio Tinto Ltd is 42.125%. Most of the generated electricity is supplied to the Rio Tinto's industrial companies that are the largest electricity consumers in the area: Boyne Aluminium Smelter, Queensland Alumina and Rio Tinto Alcan Yarwun.

It is worth noting that there are some smaller power generators in the Gladstone industrial area, and several others are expected. Rio Tinto Alcan Yarwun uses its own facilities for the combined steam and electricity generation, powered by natural gas. A private company Austicks, the only Australian manufacturer of food grade ice cream sticks, reuses its wooden waste for steam and electricity generation. Orica and Cement Australia have the opportunities to reuse their waste heat for electricity generation. QER, at a commercial scale, may develop cogeneration facility by utilising spent shale as a fuel material. The announced plans for GPNL, Boulder Steel, and all LNG projects include their own cogenerations powered by natural gas.

2.5.1 By-products and wastes

Main waste products of the coal power generation are fly ash and bottom ash. About one third of the NRG's fly ash is collected by Pozzolanic Enterprises (Cement Australia subsidiary) for its further reuse as a cementitious material, while the rest is disposed at the nearby ash dam together with the bottom ash that has not found any useful application so far.

2.5.2 Previously described opportunities and synergies

The previous report described six synergy opportunities for NRG (Corder, 2005) (Table 2.10), their present status:

- one synergy is in use (fly ash for cement production),
- one is considered for the future (bottom ash for bricks production and road base),
- two are rejected (fabric filters as an alternative fuel, and biomass fuel),
- and two synergies have not got any further investigation (waste heat recovery, and emissions utilisation).

Table 2.10 NRG – summary of synergy opportunities indicated in previous research

Suggested/existing synergy	From	To	Current status	Notes
1. Fly ash as a cement additive	NRG	CA	In use	Only one third of the total fly ash output is reused, the rest is still disposed

2. Bottom ash for the production of light weight strong bricks, soil additives and road base material	NRG	Different customers	Considered	A local bricks manufacturer is currently performing trials for the possible use of NRG's bottom ash at its facility in Gladstone
3. Fabric filters as an alternative fuel	NRG	CA	Rejected	Cause problems in kilns
4. Biomass fuel from local companies	Austicks, et al.	NRG	Rejected	Biomass fuel is suitable to use at NRG, but it can risk process stability
5. Waste heat recovery (steam generation, water desalination plant)	NRG	Different customers	N/A	No users for steam in close proximity
6. Emissions (NO_x, SO_x, CO_2) recovery/ utilisation	NRG	-	N/A	-

2.5.3 Other potential synergies

The reuse of fly ash is a widely known synergy opportunity. Nevertheless a significant part of NRG's fly ash is rejected by Pozzolanic Enterprises due to the high carbon content which makes it unsuitable to use as a cement or concrete additive. However, fly ash can also be used in clinker production (at the previous stage of cement production) as a part of raw mixture.

The production of high-carbon fly ash is typical for coal-fired power plants in the USA due to the implementation of environmental policies to reduce NO_x emissions (Bhatty et al., 2003). For an American case study, the reuse of high-carbon fly ash as a 3% addition to clinker raw mix has demonstrated a 2.6% reduction in the fuel consumption with slight increases in CO, NO_x and SO_x emissions (Bhatty et al., 2003).

The summary of other potential synergies is provided in Table 2.11. All existing and potential synergies for NRG are also illustrated in Figure 2.6.

Table 2.11 NRG – summary of other potential synergies

Suggested/existing synergy	From	To	Current status	Notes
1. Fly ash with high residual carbon content for clinker production (coal and raw meals substitute)	NRG	CA	N/A	This fly ash is currently rejected as not suitable to use as a cement additive, but may work as an additive for the previous stage – in clinker production

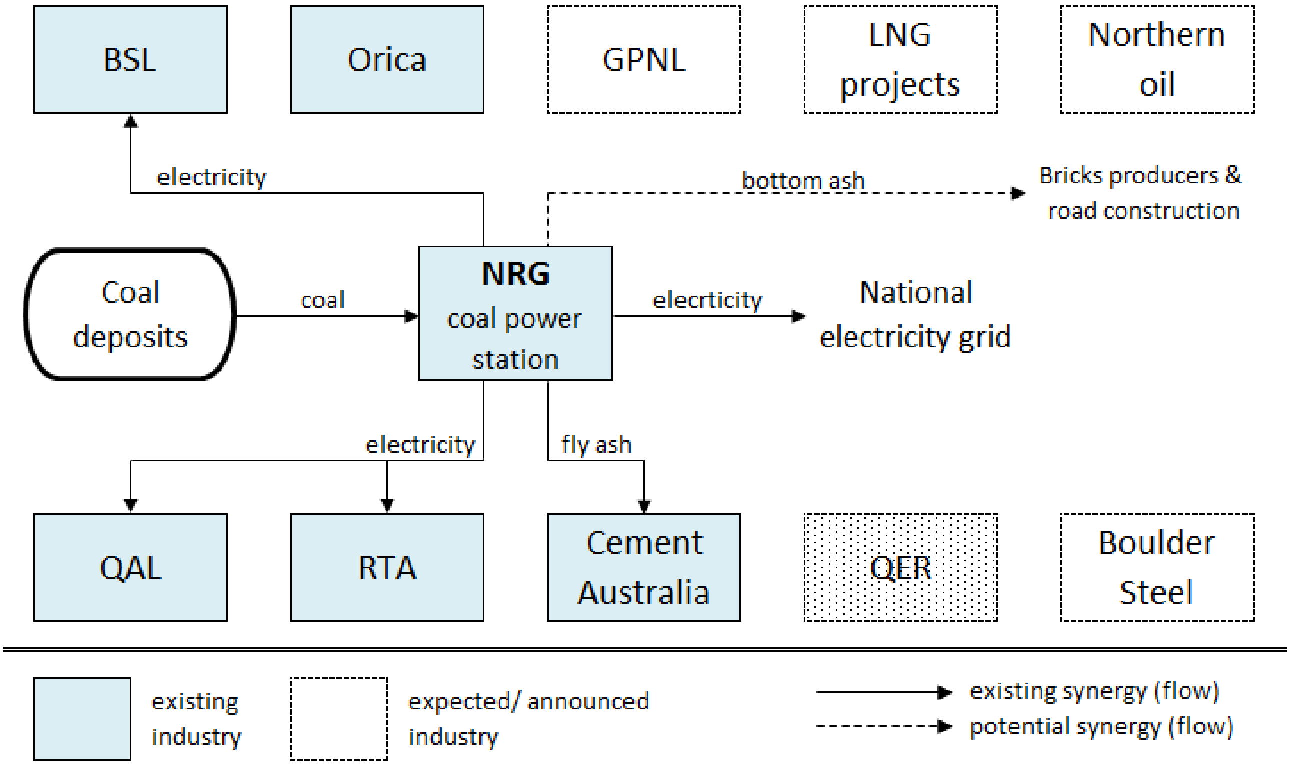


Figure 2.6 NRG: existing and potential synergies within Gladstone industrial area

2.6 Alumina refineries (QAL and RTA)

Queensland Alumina Limited (QAL) and Rio Tinto Alcan Yarwun alumina refinery (RTA) are one of the world largest alumina producers, with production capacities of 3.95 Mtpa and 3.4 Mtpa (including 2 Mtpa of stage 2 commenced in 2012) respectively, which in total represents about 9% of the world alumina production and about 35% of its production in Australia.

To date, it has not been possible to interview any of the appropriate personnel from these companies. As a result only a short description of the previously indicated synergy opportunities is included to this report.

2.6.1 By-products and wastes

Main wastes for alumina production include red mud (about 1 t per every tonne of produced alumina) and fly ash (due to the use of coal fired boilers for steam generation). Other solid wastes are generated in relatively small quantities and mostly recycled at the companies' waste transfer facilities.

2.6.2 Previously described opportunities and synergies

An observation of the publicly available reports for QAL and RTA has not found any progress for the previously suggested potential synergy opportunities. Nevertheless, both companies continuously report about their environmental efficiency improvement (QAL, 2011, RTA, 2011). A list of synergies from the previous study and some additional notes are provided in Table 2.12.

Table 2.12 QAL and RTA – summary of synergy opportunities indicated in previous research

Suggested/existing synergy	From	To	Current status	Notes
1. Secondary effluent reuse	Calliope River STP	QAL	In use	-
2. Extraction of alumina from waste saltcake (aluminium recycling process waste)	Smorgon-Steel	QAL	N/A	Aluminium scrap, dross and prills are now recycled onsite at BSL (see Table 2.6)
3. Red mud reuse (different options)	QAL/RTA	Different customers	N/A	-
4. Fly ash reuse (different options)	QAL/RTA	Different customers	N/A	Both RTA and QAL gradually decrease their reliance on coal fired boilers, replacing them by natural gas powered cogenerations
5. Waste heat reuse/ recovery	QAL/RTA	QAL/RTA	N/A	-

3 Future Industries Overview

The outline of future industries is based on regular updates of new projects development in Gladstone, provided by GEIDB, and the information from industries' reports and official web-sites (if available). The GEIDB (Gladstone Economic and Industry Development Board) is a part of the Queensland Government that facilitates investment attraction and project development in the Gladstone Region, being the first point of contact for industry proponents to discuss the opportunities and benefits of the region (http://www.gladstoneindustry.org.au/).

The following future/potential industries in Gladstone are included to this overview:

- Northern Oil Refineries Pty Ltd;
- LNG projects on Curtis Island;
- Aldoga Power Station;
- Gladstone Pacific Nickel Limited;
- Boulder Steel Limited.

3.1 Northern Oil refining plant

J.J. Richards & Sons Pty Ltd together with Southern Oil Refining Pty Ltd have proposed a used oil re-refining facility at Landing Road, Yarwun, which is expected to open in late 2014. This will be the first true used oil re-refinery in Queensland, designed to cater for the significant output of used oil from Queensland and Northern Australia. The estimated production processing is up to 100 million litres (~87,000 tonnes) of used lubricating oil a year to produce approximately 60 million litres (~52,000 tonnes) of hydrocarbon based oils for re-blending and subsequent reuse in the lubricating market.

A quantitative estimation of used oil products that can be collected from industries within Gladstone industrial area is not publicly available; however, it is likely most existing industries will use this recycling facility.

3.2 LNG projects on Curtis Island

Several large LNG (Liquefied Natural Gas) processing plants and export facilities have been proposed in Gladstone (Table 3.1). These plants predominantly represent bigger projects that comprise coal-seam gas field developments in Central Queensland, and a pipeline component to deliver raw natural gas to Gladstone.

LNG projects on Curtis Island include the development, construction and operation of an LNG plant, storage tanks and marine export facilities, plus a number of ancillary or additional activities which may be developed or conducted by others, including the dredging of marine access channels, the provision of roads and bridge access to Curtis Island including a services corridor.

Table 3.1 Proposed LNG plants on Curtis Island in Gladstone

Project	Expected year (stage 1/2)	Capacity, stage 1 (2), Mtpa	Current status
1. Queensland Curtis LNG (QGC, owned by BG Group) www.qgc.com.au	2014/?	8.5 (12)	Under construction
2. GLNG (Santos, Petronas, Total and Kogas) www.glng.com.au	2015	7.8	Under construction
3. Australian Pacific LNG (Origin and ConocoPhillips) www.aplng.com.au	2015/?	9 (18)	Under construction
4. Arrow LNG Plant (Shell Australia and PetroChina) www.arrowenergy.com.au	2016/?	8 (18)	Proposed
5. LNG Limited (HQC, owned by PetroChina) www.lnglimited.com.au	?	3	Proposed
Total		**36.3 (58.8)**	

LNG plants are relatively "clean" compared to many industrial plants. The only significant environmental impact is carbon dioxide emissions, coming from the fuel combustion for power generation and refrigeration, and raw natural gas refining. The environmental impact statements for the proposed LNG facilities in Gladstone estimate that the level of overall CO_2-eq. emissions (excluding emissions at the coal seam gas fields) will be in between 0.25 and 0.5 tonne per every tonne of LNG[3].

3.3 The Aldoga Power Station

This project proposes a high-efficiency gas-fired power station located in the Aldoga Precinct of the Gladstone State Development Area (GSDA). It is currently at the permitting process stage, and the commencement of construction is targeted for 2013. The estimated capacity for the initial unit is 500 MW, with a total power station capacity of up to 1500MW.

Modern gas-fired power stations typically produce half the carbon dioxide emissions of coal-fired stations. The co-generation of steam for industrial purposes could increase overall efficiency in both cases, but it is not a part of the original proposal. Most industries in Gladstone already have (or plan to have, in case of future industries) their own steam generation facilities.

3.4 Gladstone Pacific Nickel Limited

Gladstone Pacific Nickel Ltd (GPNL) is a nickel/cobalt refinery project in the Yarwun Precinct (near the existing Orica facilities), that consists of a high pressure acid leach (HPAL) plant and metals plant. The refinery will use the nickel laterite ore from Marlborough deposit (approximately 180 km north-west of

[3] See, for example, GLNG Project - EIS, Section 6, available at www.glng.com.au (direct link to download: http://www.glng.com.au/library/EIS/Section%206/06%2009%20Greenhouse%20Gas%20%28Section%206.9%29%20FINAL%20PUBLIC.pdf).

Gladstone) together with imported ore from the south-west Pacific region. Residue from the refinery will be pumped to a special residue storage facility (RSF) located in the Aldoga Precinct, approximately 15 km south-west of the refinery site. The estimated production level for the stage 1 is 63,000 tpa nickel and 6,000 tpa cobalt, doubled with the stage 2 (GPNL, 2007).

The GPNL project will require high levels of water consumption (about 30 GL of fresh water per year), and generate about 14 Mtpa of solid wastes (nickel residue) (GPNL, 2008). This will make GPNL the largest water consumer (and effluents emitter), and the largest solid waste generator in Gladstone.

One of the possible mitigations for these impacts is proposed in GPNL project documents (GPNL, 2007), and includes the combination of pre-neutralised alumina residue (alkaline) and GPNL residue (acidic). Even though, the mixing of these residues can give significant advantage to both GPNL and alumina refineries, it is not currently incorporated into plant design, and only indicated as a potential for project's stage 2.

Considering the close proximity of the proposed GPNL plant with RTA, Orica and Yarwun sewerage treatment plant, water related synergies may be identified if a more detailed study is performed.

Solid residues of nickel laterite ore processing include significant amount of iron oxides (about 50%, this is similar to the red mud), which makes the recovering of iron possible (see, for example: (Ema and Harada, 1987, Imanishi et al., 1987, Zhai et al., 2010).

Main potential synergies for GPNL are summarised in Table 3.2 and Figure 3.1.

Table 3.2 GPNL – summary of potential synergies

Suggested/existing synergy	From	To	Current status	Notes
1. Hydrogen sulphide supply	QER	GPNL	N/A	Will need additional feasibility study
2. Ammonia supply	QER	GPNL/ Orica	N/A	Will need additional feasibility study
3. Sulphuric acid supply	GPNL/ QER	Orica	N/A	-
4. Spent sulphuric acid recycling	Orica	GPNL/ QER	N/A	Currently recycled at Orica's facility in Port Kembla (NSW)
5. Barren liquor reuse for red mud co-neutralisation (instead of sea water), with the return of sodium-rich magnesium-depleted liquour back to make a slurry for HPAL processing	GPNL	RTA/ QAL	N/A	-
6. Laterite nickel leached residue for iron recovery	GPNL	Boulder steel	N/A	Will need additional feasibility study. Both projects are delayed

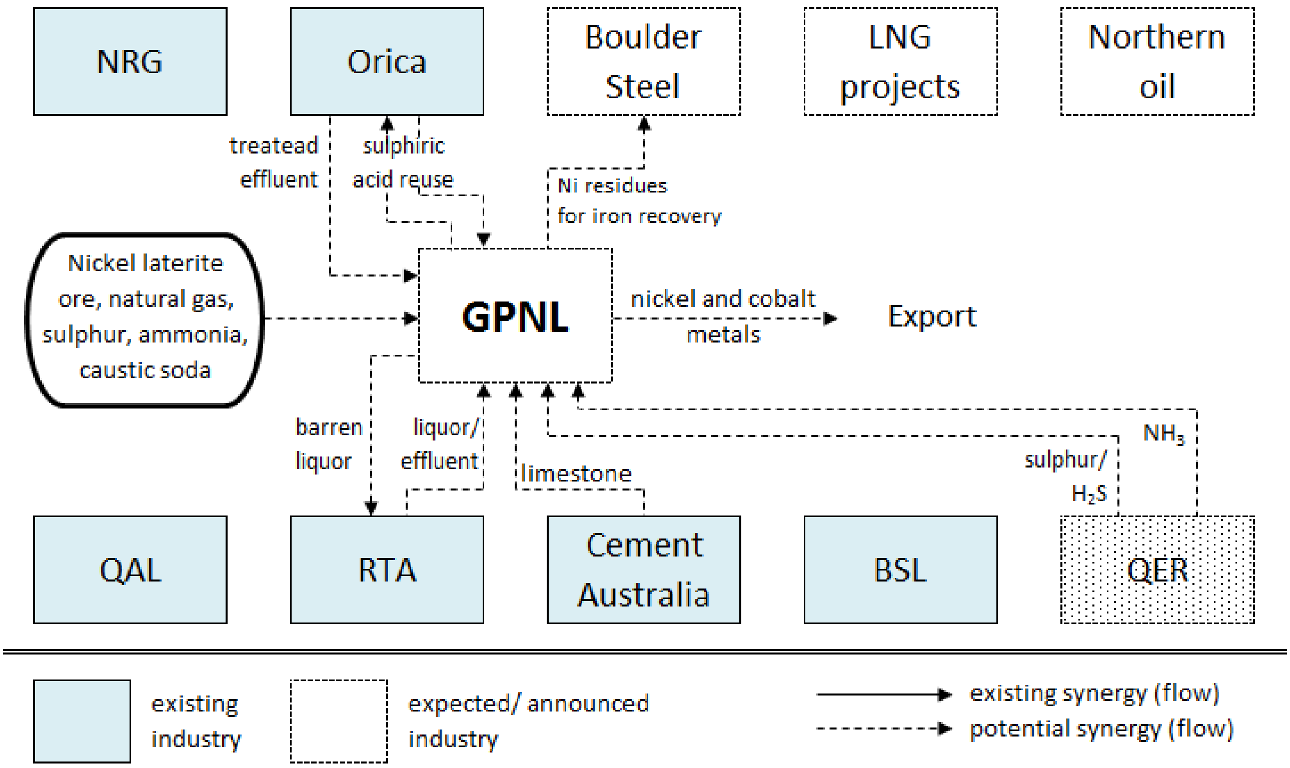


Figure 3.1 GPNL: potential synergies within Gladstone industrial area

3.5 Boulder Steel Limited

This project proposes an integrated steelmaking plant at a site within the Aldoga Precinct to produce high quality steel in bloom and round billet form (i.e. semi-finished steel) for export to overseas finishing plants. The ultimate capacity of the plant is 5 Mtpa, with an initial stage (Stage 1) of 2.1 Mtpa. Raw materials will be sourced mainly from Australia (iron ore, metallurgical coke, limestone and scrap).

Main potential synergies for Boulder Steel are summarised in Table 3.3 and Figure 3.2.

Table 3.3 Boulder Steel – summary of potential synergies

Suggested/existing synergy	From	To	Current status	Notes
1. Granulated blast furnace slag	Boulder steel	CA	N/A	Steel slag is used as a cement additive
2. Basic oxygen furnace steel slag (BOFS)	Boulder steel	CA	N/A	BOFS is preferably used as an aggregate material, but maybe also suitable for clinker/cement production
3. Met coke dust and fines as a fuel material	BSL	Boulder steel	N/A	Different types of dust are typically can be reused at a steel plant for iron recovery and as fuel substitutes
4. Laterite nickel leached residue for iron recovery	GPNL	Boulder steel	N/A	Will need additional feasibility study. Both projects are delayed

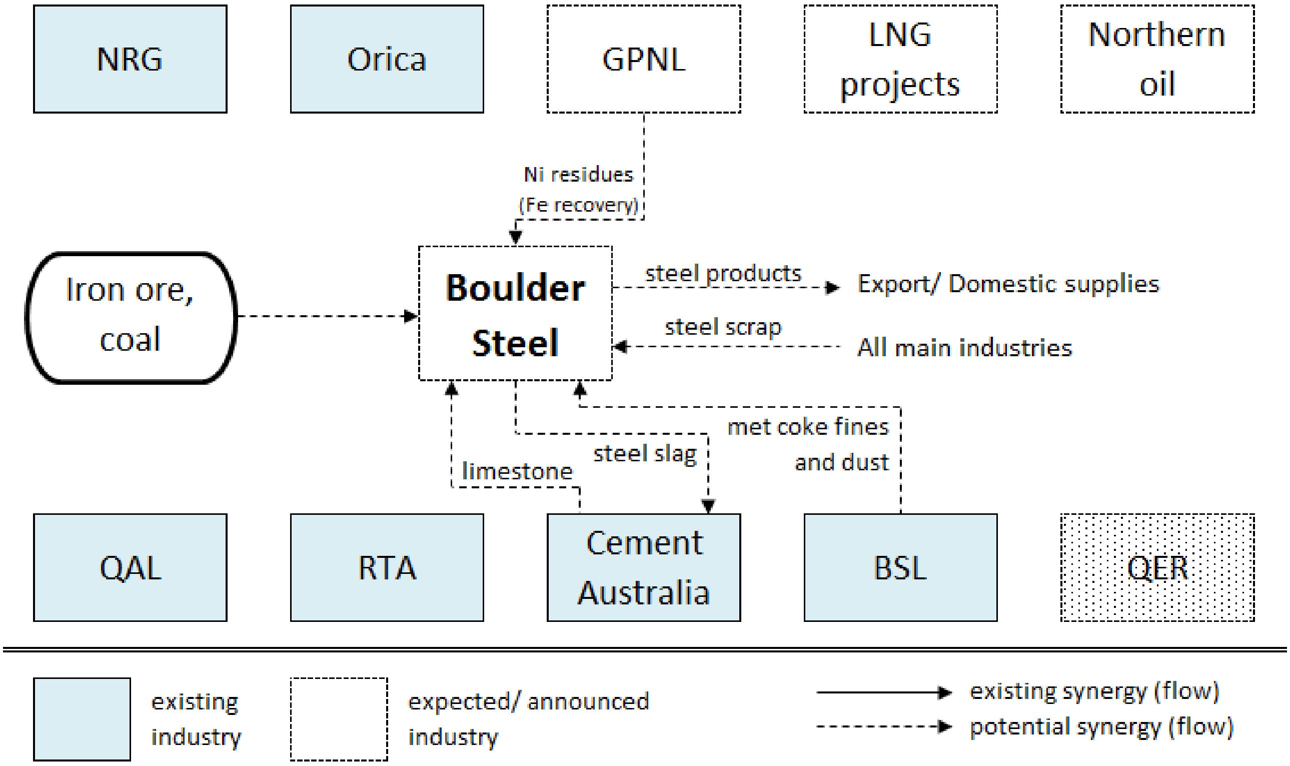


Figure 3.2 Boulder Steel: potential synergies within Gladstone industrial area

4 Existing and Potential Resource Synergies Summary

This section summarises the data from Sections 2 and 3, and compares main findings of this report with the previous research (Gladstone Regional Synergies Project 2004-2007).

4.1 Terminology notice

For comprehensive comparison of the two Gladstone studies as well as for the comparison with other regional studies, additional categorisation for synergies is used in this report.

Firstly, all detected synergies have been subdivided into three categories: 1) eco-efficiency projects at a company level, 2) regional synergies (inter-firm projects), and 3) inter-regional synergies (waste reuse projects that include collaboration between companies from different regions). Strictly speaking, projects from the first category should not be a part of regional resource synergies studies; however, in many cases, due to different reasons, these projects are also included in regional observations.

Secondly, for the comparison of synergies with different stages of implementation, the following classification is used:

- Synergies 'in use' – projects that have been already implemented and currently are in operation.
- Expected synergies – projects that industries plan to proceed with in the nearest future. Usually, these include projects where trials have been commenced or expected, and-or these solutions are well known and have been already successfully implemented elsewhere. Two synergies from those that have been indicated as being in operation in the previous report (Corder, 2005), in fact were on trials (SCL, and tyres as AFR at Cement Australia). Later, one of them was rejected (tyres), while another (SCL) proceeded and is 'in use' now.
- Delayed (or considered for the future) synergies – projects that have been recognised by industries, in some cases already have prefeasibility studies, but are rejected under current economic conditions or regulation; however, they are still considered as possible for implementation in the future if conditions change. Projects that include future expansions of existing industries may also fall in this category.
- Cancelled synergies (were in use) – projects that have been previously in use, but due to different reasons are cancelled at present.
- Rejected synergies (were not in use) – projects that were considered as possible or expected for the implementation in the past, but were rejected later after more detailed observation/trials.
- Synergies with unknown status – all other projects whose status cannot be defined within one of the previous categories. These usually include new (just recently detected) synergy opportunities, synergies with high level of uncertainties, or projects that relate to the future (expected) industries in the area.

Apart from regional resource synergies with clear environmental benefits, there may also be traditional business connections within an industrial area, such as supply chain connections. These connections for the Gladstone industrial area are recognised in this report (for example, alumina, limestone, electricity, and chlorine supplies), but they are not counted as resource synergies.

4.2 The comparison of 2004 and 2012 Gladstone studies results

From 2004 to 2012, for the observed industries in Gladstone, the number of synergies is slightly increased – from 8 to 10, including an increase from 5 to 6 for regional and inter-regional synergies (Table 4.1) [4].

Table 4.1 Regional synergies in Gladstone: comparison of 2004 and 2012 studies results

Synergy status	Eco-efficiency (within a site)		Regional synergies		Inter-regional synergies		Total		
	2004	2012	2004	2012	2004	2012	2004	2012	+/-
Synergies 'in use'	3	4	3	4	2	2	8	10	+2
Expected	1	-	2	3	-	-	3	3	-
Delayed	2	3	8	4	-	-	10	7	-3
Status is unknown	1	2	10	23	-	-	11	25	+14
Existing and potential synergies	**7**	**9**	**23**	**34**	**2**	**2**	**32**	**45**	**+13**
Cancelled (were in use in 2004)	-	n.a.	1	n.a.	-	n.a.	1	n.a.	-
Rejected (were not in use)	-	n.a.	7	n.a.	-	n.a.	7	n.a.	-
Total	**7**	**9**	**15**	**34**	**2**	**2**	**24**	**45**	**+21**

Out of the three expected synergies in 2004-2005, two have been implemented (the recycling of lime dust in clinker production, the reuse of spent cell linings from BSL as an alternative fuel material at Cement Australia), and one has been rejected (tyres as an alternative fuel material at Cement Australia). Additionally, one project has been added to the list of existing synergies – wood chips reuse as mulch (from BSL to QAL), as it was not described previously.

One of the synergies – caustic soda recovery at BSL – was cancelled for cost reasons. Two synergies, previously reported as delayed, are marked as expected now – bottom ash for bricks production and road construction, and lime dust/off specification lime reuse as a soil additive (Table 4.2).

Overall, out of 32 synergies mentioned in (Corder, 2005) report, at present:

- nine are 'in use' (including one cancelled, and two implemented),
- two are expected,
- one is canceled,
- seven are rejected,
- and 13 are still delayed or unknown (see Appendix 1 for details).

[4] Detailed list of synergies is presented in Appendix 1.

This research has also detected and summarized 21 new synergy opportunities, including 5 within existing industries and 16 that relate to the collaboration with future industries (QER – 8 synergies, GPNL – 4 synergies, Boulder Steel – 3 synergies, and Northern oil – 1). One of these synergies is 'in use' (wood chips as mulch), and one is expected (the recycling of waste lubricants by Northern oil refinery, this project is expected to commence in 2012/14), while most of the others fit the 'unknown synergies' categories, and further research is needed to assess their feasibility.

The information about all active and expected regional resource synergies in Gladstone is summarised in Table 4.2. An illustration of these synergies is also presented in Figure 4.1.

Table 4.2 List of active and expected regional resource synergies in Gladstone

Synergy	From	To	2004 status	2012 status	Notes
I. Eco-efficiency projects at a company level					
1.1. Burn-off butts are recycled and combined with petroleum coke and liquid pitch to produce new carbon anodes	BSL	BSL	In use	In use	-
1.2. Recycling of aluminium scrap, dross and prills	BSL	Smorgon-Steel / BSL (since 2010)	In use	Replaced (in use)	BSL's metal reclamation facility started in 2010. All aluminium scrap, dross and prills are recycled now onsite
1.3. Waste transfer facility	QAL	QAL	In use	In use	Operated in conjunction with Transpacific Industries, a waste management company that handles the sorting and segregation of materials for reusing or recycling
1.4. Lime dust: recycling in clinker production	CA	CA	Expected	In use	Most of lime kiln dust is reused in clinker production, the reminder is disposed
II. Regional resource synergies (inter-firm exchanges)					
2.1. Fly ash as a cement additive	NRG	CA	In use	In use	Only one third of the total fly ash output is reused, the rest is still disposed
2.2. Secondary effluent reuse	Calliope River STP	QAL	In use	In use	-
2.3. Spent cell linings (SCL) (calcined ash) as a fuel material	BSL	CA	Expected	In use	BSL covers the costs for SLC pre-drying in calciner, milling, transportation to Cement Australia, and also pays an extra fee for its reuse in clinker kiln
2.4. Bottom ash for the production of light weight strong bricks, soil additives and road base material	NRG	Different customers	Delayed	Expected	A local bricks producer is currently performing trials for the possible use of NRG's bottom ash at its facility in Gladstone
2.5. Lime dust/ off specification lime as a soil additive	CA	Different customers	Delayed	Expected	Potential reuse in soil remediation on Curtis Island (construction work for new LNG plants)

Synergy	From	To	2004 status	2012 status	Notes
2.6. Alternative fuel materials: tyres	Different suppliers	CA	Expected	Rejected	No detailed technical explanation is available
2.7. The production of caustic soda (low concentration) from SCL	BSL	QAL/QER	In use	Cancelled	Not feasible in comparison with SLC's direct disposal and-or reuse as an alternative fuel at CA
2.8. Wood chips production from waste wood and timber (used for mulch)	BSL	QAL	-	In use	Mulch is reused for weeds suppression
2.9. Refining of waste lubricants (to produce a wide range of usable lubricant products)	Different suppliers	Northern oil	-	Expected	Construction and commissioning stage for Northern oil project is 2012/14
III. Other resource synergies (inter-regional exchanges)					
3.1. Fertiliser solution (60% ammonium nitrate)	Orica	Agricultural companies	In use	In use	The demand is seasonal, the alternatives are still under investigation
3.2. Alternative fuel materials: solvent-based fuels	Geocycle	CA	In use	In use	Geocycle Pty Ltd is a part of the Cement Australia Group

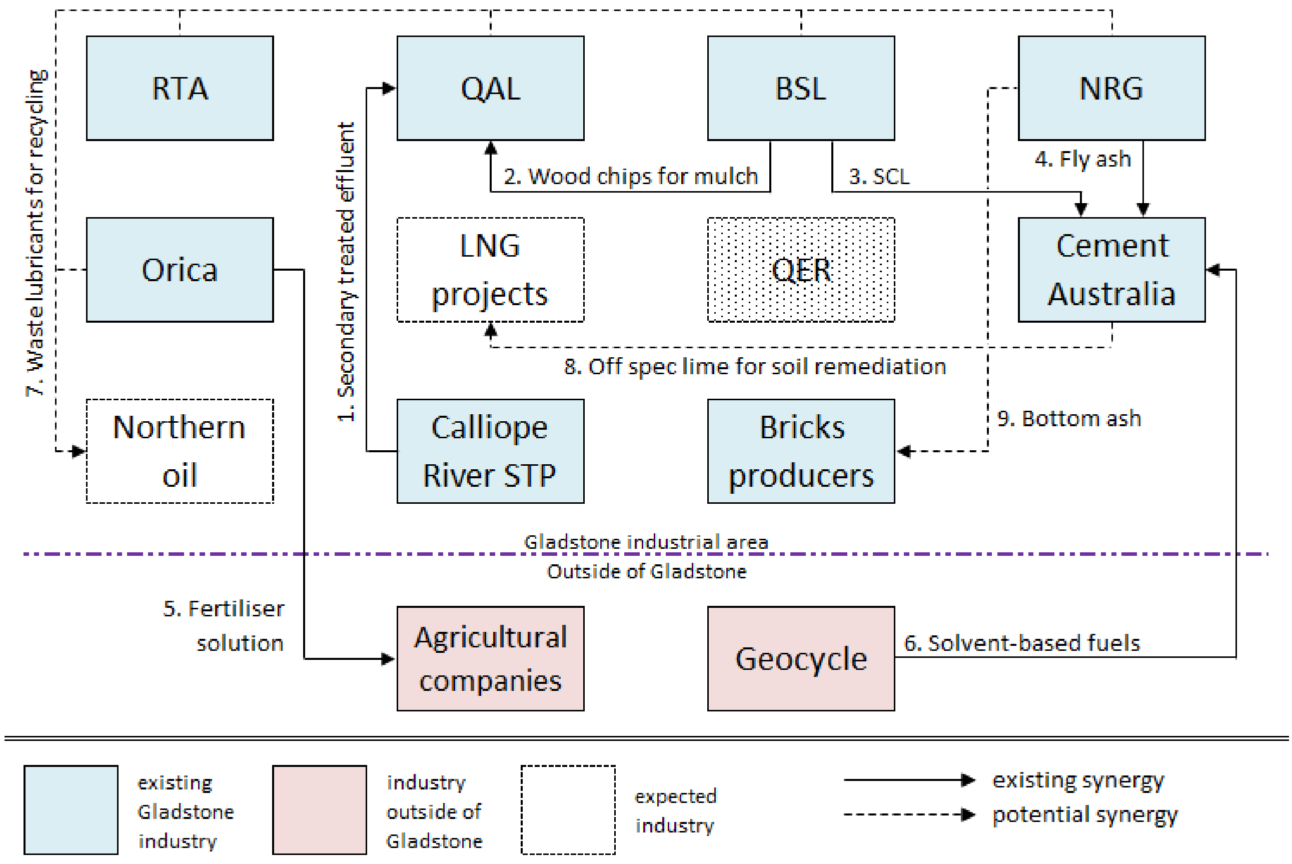


Figure 4.1 Gladstone industrial area: existing and expected resource synergies

The most significant future potential synergies are mapped in Figure 4.2 (see Appendix 1 for details).

The number of synergy opportunities for the Gladstone industrial area that have been revealed in this and previous research is quite significant. However, the industries' interest in further investigation of these opportunities is still unclear.

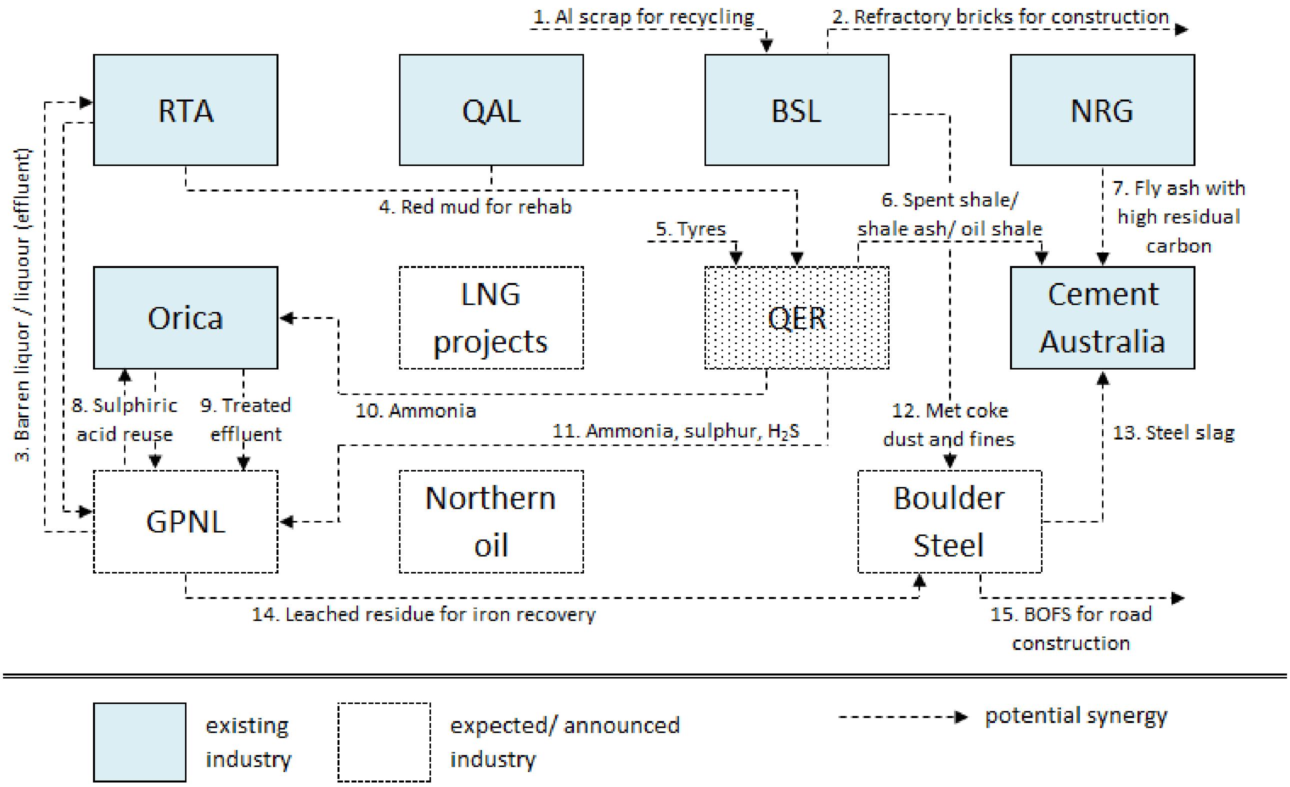


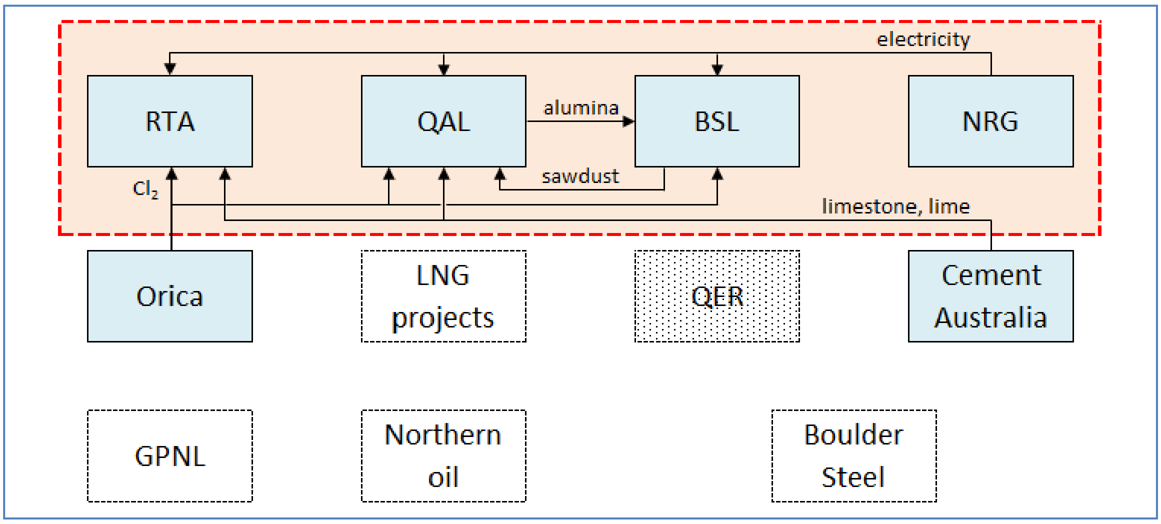
Figure 4.2 Gladstone industrial area: future potential resource synergies

4.3 Synergies clusters

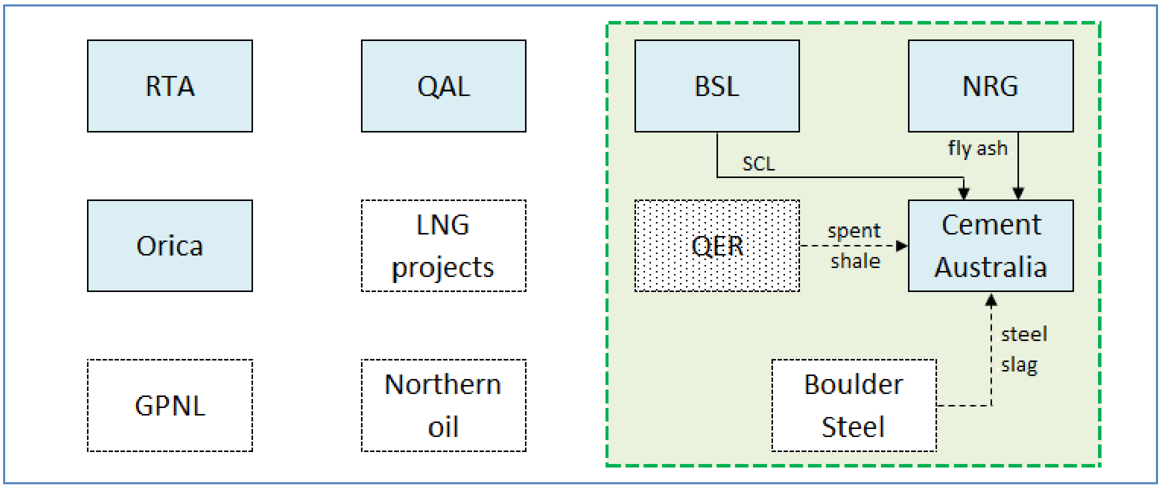
Several existing and potential clusters, based on a combination of similar synergy opportunities, industries' affiliation, and geographic location, can be defined within the Gladstone industrial area (Figure 4.3):

- **Business cluster** (Rio Tinto Group) – includes value chain connections between industries that are a part of Rio Tinto Group (QAL, RTA, BSL, and NRG), plus supply connections of these industries with Orica and Cement Australia,
- **Alternative raw materials and fuels for cement production' cluster** – includes supplies of different waste materials to Cement Australia that are used as alternative fuel and-or raw material,
- **Water cascading cluster** (water reuse and waste co-neutralisation) – includes potential water links between situated in a close proximity at Yarwun site Orica, RTA, and future GPNL plant.

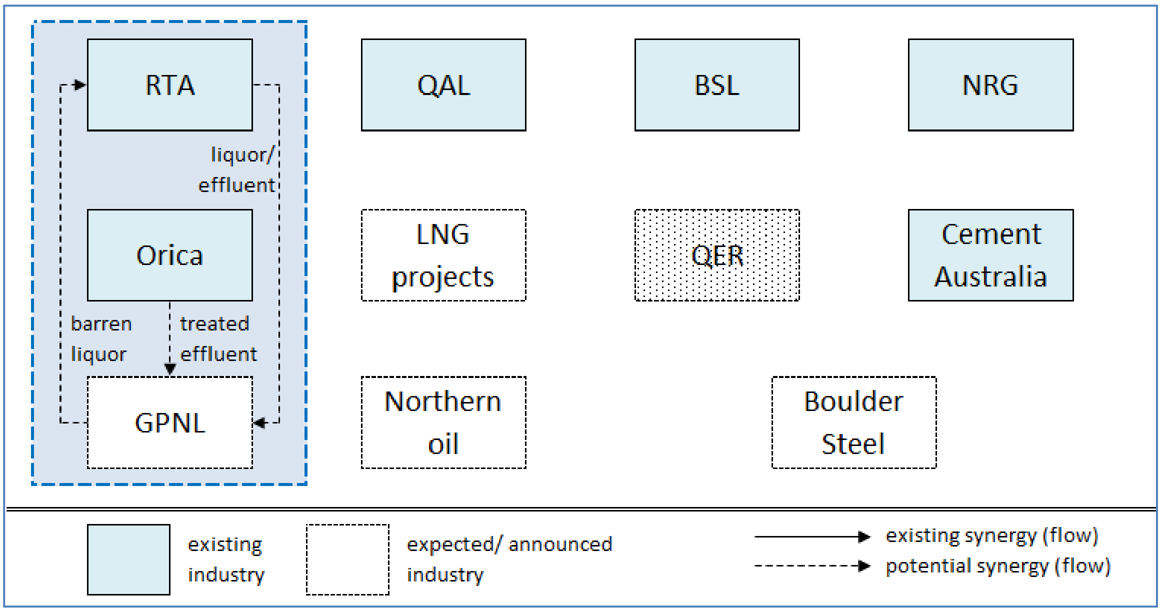
This approach can be used to facilitate further investigation of synergies mentioned in this report, as well as for the discovery of new opportunities with active involvement of respective industries.



a) Business cluster – Rio Tinto Group



b) Alternative raw materials and fuels for cement production' cluster



c) Water cascading cluster (water reuse and waste co-neutralisation)

Figure 4.3 Gladstone industrial area: existing and potential synergies clusters

5 Main Waste Streams: Current Situation and Future Changes

Main industrial waste streams that have not found yet a useful application in Gladstone include red mud, fly ash (less than one third is reused as cementitious material), bottom ash, construction wastes (concrete and refractory bricks), and met coke fines (Table 5.1).

Table 5.1 Solid waste streams in Gladstone industrial area (2011)

Waste material	Generator(s)	Quantity*, ktpa	Current utilisation	Possible reuse
1. Red mud	QAL, RTA	~5000	Disposed in red mud dams	Building materials, iron and other metallic constituents recovery, land fill, CO_2 sequestration
2. Fly ash (disposed)	NRG, QAL, RTA	~400	Disposed in fly ash dams (NRG, QAL), or together with red mud (RTA)	Building materials, road sub-base, zeolite synthesis, low cost adsorbent, mine back fill
3. Bottom ash	NRG	~50	Disposed in fly ash dams	Bricks production, road construction
4. Construction wastes	Different industries	~10	Stockpiled or disposed at landfills	Building materials, road construction
5. Met coke fines	BSL	~1	Disposed at landfills	An alternative fuel material

** Author's assumption based on (Corder, 2005) and companies' public reports.*

In comparison with 2004, no significant changes in the utilisation of main waste streams have yet happened (Table 5.1). The only new expected project is the reuse of NRG's bottom ash for bricks production that is currently investigated by a local manufacturer in Gladstone.

New industries, coming to Gladstone, will bring additional solid wastes, emissions, and effluents with limited available/feasible reuse option. An estimation of these future waste streams for 2020, based on companies' environmental impact statements (if available) and existing literature, is presented in Table 5.2.

The most significant expected influence on the level of solid wastes generation and water effluents (up to 80% overall) relates to the GPNL project due to its large volume waste streams. It is estimated from this analysis that the amount of solid wastes is expected to increase by four times (+300% growth), while water effluents to Port Curtis will double (+100%).

An increase in carbon dioxide emissions is expected with the commencement of LNG plants on Curtis Island. Considering other new projects and expansions of existing industries, it is estimated that CO_2-eq. emissions for the Gladstone area will increase three times (+200%) from 2011 to 2020.

Table 5.2 Gladstone 2020: estimation of increase in environmental impacts

Waste material and its generator	Expected year	Quantity, ktpa (ML)	Growth (2020/ 2011)	Proposed utilisation	Notes
1. Solid wastes	**2020**	**~19,050**	**+ 300%**		
- red mud (RTA, stage 2)	2012/13	~2,000	-	Red mud dam disposal	Estimation based on (Corder, 2005)
- nickel plant residue (stage 1 and 2)	2016/20	~14,000	-	To pump and dispose at a special storage facility	(GPNL, 2008)
- spent shale (QER, stage 1)	2016/20	~1,400	-	Mine backfilling	Estimation based on QER's website and Section 2.1
- granulated blast furnace slag (Bolder Steel, stage 1 and 2)	2016/20	~1,400	-	Reuse in cement and construction industry	(Boulder Steel Ltd, 2011)
- basic oxygen furnace steel slag (Bolder Steel)	2016/20	~250	-	Reuse in construction industry (roads)	(Boulder Steel Ltd, 2011)
2. Neutralised and-or diluted water effluents discharge to Port Curtis	**2020**	**~35,000**	**+ 100%**		
- RTA, stage 2	2012/13	~5,000	-	No	Estimation based on (Corder, 2005)
- GPNL (stage 1 and 2)	2016/20	~30,000	-	No	(GPNL, 2008)
3. CO_2 emissions	**2020**	**~39,000**	**+ 200%**		
- RTA, stage 2	2012/13	~1,000	-	No	Estimation based on (Corder, 2005)
- Aldoga power station (1500 MW)	2014/16	~5,000	-	No	~0.4 kg CO_2 per kWh (Hawkes, 2010)
- LNG plants (total capacity 59 Mtpa)	2014/20	~20,500	-	No	Estimation based on LNG projects EIS (Section 3.2)
- QER (stage 1)	2016/20	~500	-	No	Estimation based on QER's website and Section 2.1
- Boulder steel (stage 1 and 2)	2016/20	~10,000	-	No	~2 t CO_2 per tonne of steel (Kim and Worrell, 2002)
- GPNL (stage 1 and 2)	2016/20	~2,000	-	No	Estimation based on (GPNL, 2007, GPNL, 2008)

6 Industrial Symbiosis Maturity Analysis

This section contains the results of the analysis of barriers to Industrial Ecology in the Gladstone industrial area. It is based on the qualitative data, collected from interviewing industries' representatives (predominantly environmental managers), and complements the material flows data analysis presented in the previous sections.

6.1 Methodology overview

To monitor and assess the level of regional industrial collaboration, an additional tool, Industrial Symbiosis Maturity Grid, was developed by the author (Table 6.1). It captures the understanding of two key aspects:

- the importance of evolutionary changes in eco-industrial development of a region, and
- the need for a better understanding of the kernels and precursors that enable IS projects to mature and thrive, which, in turn, assist with the development of regional sustainability strategies.

Maturity grids have been successfully used, since their rediscovery in 1990s, to assess strategic and operative capabilities in an organisation for quality management, product development, communication, data security, risk management, etc. (Maier et al., 2009). They have not, however, been applied at a regional scale and for inter-industry co-operative initiatives.

The proposed IS Maturity Grid (see Table 6.1) includes seven barriers that are tested against five stages of maturity. Detailed descriptions are used to characterise every section in the grid. Where an industrial region lies on the grid (in other words, the level of maturity) is determined from interviews with different stakeholders and industries' representatives, plus analysing additional supporting/clarifying information and data. This tool also helps to indicate a potential path for further improvement and development in an industrial region, depending on where that region currently lies in the grid.

The grid is used when interviewing the industries' representatives and other key stakeholders (government bodies, inter-industry organizations, community environmental groups, etc.). It includes a series of open-based questions and general discussion about the region in regards to industrial collaboration and development. The answers to these questions are used to interpret the level of maturity in each of the seven themes for the region in grid (Table 6.1).

Table 6.1 Industrial Symbiosis Maturity Grid (source: authors)

Barriers to industrial ecology	Stage 1 Uncertainty (not recognised)	Stage 2 Awakening (initial efforts)	Stage 3 Enlightenment (active)	Stage 4 Wisdom (proactive)	Stage 5 Certainty (forming the future)
Commitment to sustainable development (SD)	SD is not recognised as a part of business strategy and practice	SD is a part of companies' strategy, but no indicators are used to measure the SD performance	Some SD indicators are used and reported, but there is a lack of proven methods/skills to standardise this process	The system of indicators and proven methods are used to ensure that the SD goals are effectively deployed to every level of the company and successfully achieved	Long-term perspectives and benefits dominate in decision-making process. Local industries cooperatively take the responsibility for the regional SD
Information	There is no exchange of information between companies in the area. Minimum environmental data is released to the public domain	Most companies release environmental reports that are publicly available, but there is a lack of detailed information on waste streams	Environmental reporting for public interest is a standard practice. Some reports that combine the information in order to see the 'full picture' may also exist	Summary of the overall environmental situation in the area is released regularly. There is an agreed coordination mechanism (or body) for the environmental data sharing and analysis	The database on existing waste streams in the area is regularly updated and well maintained. Any additional details can be easily obtained through existing communication system
Cooperation	Every company looks solely for its waste reuse opportunities. There is a lack of trust between companies that hampers any collaboration	Cooperation between industries predominantly happens when they are facing serious challenges together	There is growing interest (and trust) for cooperation with neighbouring industries. Coordination for these initiatives is predominantly lies at the top management level	Cooperation between companies in the area happens often in different spheres. Coordination for these initiatives is gradually proceeds from the top level to lower levels	Cooperation between companies is constructive, happens regularly at different levels. There is continuous effort to improve it
Technical	The waste reuse opportunities outside of a single company are not considered to be worthwhile. Costs minimisation for the waste disposal is preferable strategy	Some opportunities for waste reuse between industries may exist, but only well known and proven projects can proceed with implementation	Several possibilities for waste reuse in the area have been identified, but there is still not enough information to proceed with these projects	Opportunities for waste reuse were analysed in detail by experts. The most promising projects have been realised, others are under further investigation	There is a list of long-term research projects for the waste reuse and minimisation, industries often proceed to the implementation as pioneers. Current level of technical expertise is at the edge of scientific progress
Regulation	Waste reuse opportunities are not well recognised in the current legislation. The regulation is more restrictive rather than encouraging	Recycling is announced in legislation as an important element, but no specific regulation exists. Decisions are usually made on the case by case basis	Recycling and waste reuse issues are an integral part of current regulation. Several well known examples are included in official documents to encourage the implementation of the best known waste reuse practices	Legislation recognises both well known and potential waste reuse options. There is continuous improvement of regulation for better environmental outcomes	Recycling and waste reuse is the main focus of environmental regulation. Most recyclable wastes are forbidden for disposal (compulsory recycling). Taxation system makes reuse option strongly preferable for most types of wastes
Community	Community is not recognised as an equal part in negotiation process for industrial development, that mostly depends on the government policy and investors interests	Community opinion maybe important in some situations, people are kept informed about most important environmental aspects	Informing community about environmental issues is a part of business strategy. There is a well established communication system. The feedback and any community members claims are well analysed, responded and reported	Contribution to community capacities is recognised as one of the most important outcomes of industrial development in the area. An official community body exists and effectively negotiate with industries and government, it may also participate in environmental assessments	Community is an active power in decision making process for the current and future industrial development in the region
Economic	Maximising of profit is the main driver for the industrial development in the region	Industries have a special budget for environmental projects to comply with current regulation. General opinion is that environmental projects sound good, but are too costly	There is an understanding that wastes maybe a valuable resource. The information on costs for the disposal of every tonne of wastes is well known and used in decision making	Waste reuse projects have proven their efficiency. There is a continuous investigation for new opportunities. Long-term benefits and risks are considered as a priority for projects approval. Some projects have been accepted even if they are not feasible from a short-term perspective	Close collaboration with other industries in the area is seen as a key competitive advantage. "By the reuse of wastes we make profit, secure our resources base, minimise environmental risks, and ensure regional SD"

6.2 Analysis of the results

The list of interviewees was formed according to the research plan, and includes the representatives of all main industries in Gladstone (apart of those who declined to participate at this stage), plus two important stakeholders in the area – Gladstone Economic and Industry Development Board (GEIDB) and Gladstone Industrial Leadership Group (GILG) (Table 6.2).

Table 6.2 List of interviewees

Name	Organisation	Position	Date of interview
1. Ms Victoria Elder	Cement Australia	Environment & Health Manager Manufacturing	20-02-2012
2. Mr George Bennetts	NRG Gladstone Power station	Manager Health, Safety, Environment & Communities	21-02-2012
3. Dr Ken King	Gladstone Economic and Industry Development Board (GEIDB)	Chief Executive Officer	21-02-2012
4. Ms Nicole Henry	Boyne Smelters Ltd	Superintendent – Environmental & Analytical Services	22-02-2012
5. Ms Fleur Laird	Orica (Yarwun site)	Environmental Manager	23-02-2012
6. Mr Lockie McGaw	JJ Richards	Gladstone Regional Manager	23-02-2012
7. Mr Chris Anderson	Queensland Energy Resources Pty Ltd (QER)	Operations Manager	24-02-2012
8. Mr Kurt Heidecker	Gladstone Industrial Leadership Group (GILG)	Chief Executive Officer	22-05-2012
9. N.A.	Queensland Alumina Ltd (QAL)	N.A.	Declined
10. N.A.	Rio Tinto Alcan Yarwun Pty Ltd (RTA)	N.A.	Declined

The answers from eight interviewed people are plotted in Table 6.3. The average score is about 3 (2.97), which positions the Gladstone industrial area at the third stage (Enlightenment) of IS maturity. The highest score was in the "cooperation" section, 3.50, and the lowest was for information barriers, 2.44. In other words, the cooperation and trust among industries is the strongest characteristic of the Gladstone industrial area, while information barriers (or the lack of information), that prevent further improvement in regional synergies development and their uptake, still exist and currently dominate among others barriers.

Table 6.3 also shows some variations in answers for the different types of barriers. The minimum variation (that is the greatest level of agreement) has been detected for "cooperation"; all received marks fit in the third and fourth squares. Most interviewees admitted that a significant improvement in cooperation and trust among industries has been achieved during the last several years, and that it is relatively easy to work together in the area for commercial, as well as non-commercial projects.

At the same time, the information barriers section had a significant variation (lowest level of agreement); the answers vary from one to four (Table 6.3). The information about existing industrial waste streams is the starting point for new potential synergies detection. In Gladstone, there is minimal public domain information. Moreover, an attempt to collect the 2011 material input-output information for this project directly from industries (in order to compare it with the previous similar research) was just partially successful. The fact that for projects in which industries are already actively involved in, there are a few barriers for the data exchange between participants – as it was mentioned by some interviewees – does not mean that relevant information is readily available for new potential synergies.

Table 6.3 IS maturity analysis: interviews' results

Barriers to industrial ecology	Level of maturity					Total answers	**Score**
	1 Uncertainty	2 Awakening	3 Enlightenment	4 Wisdom	5 Certainty		
Commitment to SD		✓	✓ ✓✓ ✓	✓ ✓✓		8	3.25
Information	✓✓	✓ ✓	✓ ✓ ✓	✓		8	2.44
Cooperation			✓✓✓ ✓	✓ ✓✓✓		8	3.50
Technical		✓✓ ✓	✓✓ ✓	✓✓		8	3.00
Regulation		✓✓✓	✓✓	✓✓✓		8	3.00
Community		✓✓ ✓	✓ ✓✓✓	✓		8	2.75
Economic		✓✓✓ ✓	✓ ✓	✓✓		8	2.88
Total answers	2	15	21.5	17.5	0	56	-
Score							**2.97**

As to the individual estimations of IS maturity in the area, they vary from 2.43 to 3.86, with the median of 2.89, while the average score is 2.97. The standard deviation is 0.45, which gives the ±0.30 variance for the 90% level of confidence. In other words, for this study and its sample, considering possible errors in answers from the individual interviewees, we can be 90% sure that the average score lies in between 2.67 (2.97-0.30) and 3.27 (2.97+0.30). This gives enough confidence to locate the Gladstone industrial area at the stage of "Enlightenment" on the IS maturity grid. The final characteristic of Gladstone's IS maturity is provided in the table below.

Table 6.4 Gladstone IS maturity analysis results

IE barrier	IS maturity score and its variation	Characteristic of Gladstone's IS maturity stage	Examples of comments from interviewees
1. Commitment to sustainable development (SD)	3.25 (2.5-4)	SD is a part of companies' strategy. The system of indicators and proven methods are used to ensure that the SD goals are effectively deployed to every level of the company and successfully achieved	"The company has targets to decrease environmental impacts on an annual basis". "The company does a lot to ensure that sustainable development is included in each of the business plans. We have targets for each department, targets for the site, continual improvement etc."
2. Information	2.44 (1-4)	Minimum environmental data is released to the public domain. There is a lack of detailed information on waste streams	"We are open to talk with other industries, but it's more ad-hoc". "We release only general information, and talk very little about our wastes". "We are happy to share the information with other interested industries if they contact us"
3. Cooperation	3.50 (3-4)	There is a matured trust and interest for cooperation with neighbouring industries. Coordination for these initiatives gradually proceeds from the top level to lower levels	"We have good relations with all main industries due to the existing business links". "We have regular meetings with other industries... but waste has not been a 'big fighter' for them"
4. Technical	3.00 (2-4)	Opportunities for waste reuse between industries may exist, but only well known and proven projects can proceed. Several possibilities for waste reuse in the area have been already identified, but there is still not enough information to proceed with these projects	"In many cases we just send wastes to the dump, pay the money and that is it"
5. Regulation	3.00 (2-4)	Recycling and waste reuse issues are an integral part of current regulation. Several well known examples are included in official documents to encourage the implementation of the best known waste reuse practices	"Some positive changes started to happen just recently. Still, they (legislation and government) do not give us any direction or encouragement". "...the biggest issue is going to be the condition in everybody's licence that allows to accept waste materials"
6. Community	2.75 (2-4)	Overall, community opinion maybe important in some situations and people are kept informed about most important environmental aspects. Some companies, that are situated in a close proximity, have a well established communication system to receive and respond to any community members claims	"Community is recognised here as being an important aspect". "Community consultations are performed only when and where there are some concerns about our activities from the local community"
7. Economic	2.88 (2-4)	Industries have a special budget for environmental projects to comply with current regulation. General opinion is that environmental projects sound good, but they are costly. The information on costs for the disposal of every tonne of wastes is usually well known	"Some environmental programs, that we implement, are not legally compulsory, but they allow us to keep (potentially) good relations with the community". "...we must provide a return for our shareholders"
Total	**2.97**	**Enlightenment (active) stage**	

7 Key Conclusions and Recommendations

An overview of the existing and future industries in the Gladstone industrial area (Sections 2 and 3) has revealed significant potential for the development of regional resource synergies. A summary of the existing and potential synergies, and the comparison of this research findings with the previous 2004-2007 project (Section 4) have displayed a slight increase in the number of regional resource synergies ‘in use’ for 2012 (from five to six). Based on this indicator of number of synergy connections, the Gladstone industrial area is less advanced compared with other well known industrial symbiosis examples in Australia and overseas.

The estimation of the future waste streams for 2020 (Section 5) shows a likely large growth of environmental impacts in the area, including four times growth of solid wastes, double water effluents and triple carbon dioxide emissions. This can be partly mitigated by a higher uptake of the suggested regional resource synergies.

Among the announced future industries development in Gladstone, QER oil shale has been overviewed as the most promising. It notably surpasses other projects in terms of both number of potential synergies, and their significance to alleviate some of the existing environmental impacts. Nevertheless, most previously detected and newly revealed synergy opportunities for the waste materials, water and energy reuse in the Gladstone industrial area still require a further investigation.

The analysis from interviewing industries representatives (Section 6) to better understand the barriers for further industrial symbiosis development has indicated that the strongest characteristic of the Gladstone industrial area is the ‘cooperation and trust’ among main existing industries. However, the analysis also indicated that greater availability of the environmental information in a public domain and its sharing between industries and other stakeholders would significantly benefit industrial symbiosis development.

The role that the community plays in changing the behaviour and approaches that different industries adopt for their business strategies in Gladstone have been already recognised. However, the potential of this influence and the formation of a stronger community vision for the sustainable development of the area, including regional resource synergies projects, still have to be explored.

The main recommendations from this research are:

- A further investigation for the most attractive synergy opportunities with active participation of the respective industries (Sections 4.2 and 4.3);
- A more detailed analysis of the information sharing system and networking connections within Gladstone industrial area, including the clarification of the role that different stakeholders play, such as industrial collaborative institutions (Gladstone Industrial Leadership Group, Gladstone Engineering Alliance, and others), community environmental groups, and government bodies.

8 Acknowledgements

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Appendix 1.
List of resource synergy opportunities in Gladstone industrial area

Suggested/existing synergy	From	To	2004 status	2012 status	Notes
I. Eco-efficiency projects at a company level					
1.1. Burn-off butts are recycled and combined with petroleum coke and liquid pitch to produce new carbon anodes	BSL	BSL	In use	In use	-
1.2. Recycling of aluminium scrap, dross and prills	BSL	Smorgon-Steel / BSL (since 2010)	In use	Replaced (in use)	BSL's metal reclamation facility started in 2010. All aluminium scrap, dross and prills are recycled now onsite
1.3. Waste transfer facility	QAL	QAL	In use	In use	Operated in conjunction with Transpacific Industries, a waste management company that handles the sorting and segregation of materials for reusing or recycling
1.4. Lime dust: recycling in clinker production	CA	CA	Expected	In use	Most of lime kiln dust is reused in clinker production, the reminder is disposed
1.5. Waste heat recovery (electricity and steam generation)	Orica	Orica, et al.	Delayed	Delayed	Potential project, not feasible currently
1.6. The use of waste heat (500°C) to pre-heat shale, generate steam and electricity	QER	QER	Delayed	Delayed	Considered as an option for the full-scale operation. Will need additional feasibility study
1.7. Waste heat reuse/ recovery	QAL/RTA	QAL/RTA	N/A	N/A	-
1.8. Spent shale as waste fuel for steam/ electricity generation	QER	QER	-	Delayed (full-scale)	Will need additional tests and feasibility study
1.9. Waste heat reuse for electricity generation	CA	CA	-	N/A	-
II. Regional resource synergies (inter-firm exchanges)					
2.1. Fly ash as a cement additive	NRG	CA	In use	In use	Only one third of the total fly ash output is reused, the rest is still disposed

Suggested/existing synergy	From	To	2004 status	2012 status	Notes
2.2. Secondary effluent reuse	Calliope River STP	QAL	In use	In use	-
2.3. The production of caustic soda (low concentration) from SCL	BSL	QAL/QER	In use	Cancelled	Not feasible in comparison with direct disposal and-or reuse as an alternative fuel at CA
2.4. Spent cell linings (SCL) (calcined ash) as a fuel material	BSL	CA	Expected	In use	BSL covers the costs for SLC pre-drying in calciner, milling, transportation to Cement Australia, and also pays an extra fee for its reuse in clinker kiln
2.5. Lime dust/ off specification lime as a soil additive	CA	Different customers	Delayed	Expected	Potential reuse in soil remediation on Curtis Island (construction work for new LNG plants)
2.6. Bottom ash for the production of light weight strong bricks, soil additives and road base material	NRG	Different customers	Delayed	Expected	A local bricks producer is currently performing trials for the possible use of NRG's bottom ash at its facility in Gladstone
2.7. Refining of waste lubricants (to produce a wide range of usable lubricant products)	Different suppliers	Northern oil	-	Expected	Construction and commissioning stage for Northern oil project is 2012/14
2.8. To feed old tyres to the process to extract their oils and reduce oil shale consumption	Different suppliers	QER	Delayed	Delayed	Further investigation and feasibility study are expected
2.9. Recovery of ammonia from the sour gas	QER	Orica/ GPNL	Delayed	Delayed	Considered as an option for the full-scale operation. Will need additional feasibility study
2.10. Water reuse from waste transfer facility	WTP	Orica	Delayed	Delayed	Potential project, being investigated
2.11. Biomass fuel from local companies	Austicks, et al.	NRG	Delayed	Rejected	Biomass fuel is suitable to use at NRG, but it can risk process stability
2.12. Alternative fuel materials: tyres	Different suppliers	CA	Expected	Rejected	Cause problems in kilns; handling issues have to be resolved first
2.13. Alternative fuel materials: boxes, bags, poly-propylene wrapping, fabric filters, oily wastes	Orica/BSL/ NRG/ QAL/RTA	CA	Delayed	Rejected	Cause problems in kilns; handling issues have to be resolved first. No detailed technical explanation is available
2.14. Brine filter cake (Ca and Mg salts, fibre) for land reclamation	Orica	CQPA	N/A	Rejected	Filter cakes are regulated waste, transported to a special landfill near Brisbane
2.15. Collective purchasing scheme for commodities, such as caustic soda	Orica/QAL/ RTA	Orica/QAL/ RTA	N/A	Rejected	-

Suggested/existing synergy	From	To	2004 status	2012 status	Notes
2.16. The use of red mud as a backfill for the mine	QAL/RTA	QER	N/A	Rejected	No need. The amount of waste materials (spent shale and overburden) will be enough to back-fill the mine. The red mud maybe considered as a part of the cover material mix for land rehab
2.17. Met coke dust and fines as a fuel material	BSL	CA/NRG	Delayed	Rejected	Possibly, due to the low calorific value. Could be also made into briquettes for fuel
2.18. Reuse of refractory bricks as a construction material	BSL	Different customers	N/A	N/A	Stockpiled for possible reuse
2.19. Emissions (NOx, SOx, CO2) recovery/ utilisation	NRG	-	N/A	N/A	-
2.20. Waste heat recovery (steam generation, water desalination plant)	NRG	Different customers	N/A	N/A	No users for steam in close proximity
2.21. Red mud reuse (different options)	QAL/RTA	Different customers	N/A	N/A	-
2.22. Fly ash reuse (different options)	QAL/RTA	Different customers	N/A	N/A	Both RTA and QAL gradually decrease their reliance on coal fired boilers, replacing them by natural gas powered cogenerations
2.23. Processed shale as a cement additive	QER	CA	N/A	N/A	Unlikely to use as a cement additive due to the high carbon content in the spent shale, but maybe suitable for clinker production (see Section 2.1.3)
2.24. Extraction of alumina from waste saltcake (aluminium recycling process waste)	Smorgon-Steel	QAL	N/A	N/A	Aluminium scrap, dross and prills are now recycled onsite at BSL (see Section 2.3.2)
2.25. Wood chips production from waste wood and timber (used for mulch)	BSL	QAL	-	In use	-
2.26. Sulphur based chemicals manufacture (utilisation of hydrogen sulphide)	QER	CA/Orica/ QAL/RTA/ NRG/BSL	-	Delayed (full-scale)	Will need additional feasibility study. The manufacture of specific chemicals may depend on its feasibility and market conditions
2.27. Aluminium scrap recycling (sourced outside BSL)	Different suppliers	BSL	-	N/A	-
2.28. Fly ash with high residual carbon content for clinker production (coal and raw meals substitute)	NRG	CA	-	N/A	This fly ash is currently rejected as not suitable to use as a cement additive, but may be added to the raw mixture (clinker production)

Suggested/existing synergy	From	To	2004 status	2012 status	Notes
2.29. Red mud for clinker production (raw meals substitute)	QAL/RTA	CA	-	N/A	The reuse of red mud for this purpose is limited to 1-5 wt% of the raw mixture
2.30. Oil shale (oil shale with low oil yield) for clinker production (coal and raw meals substitute)	QER	CA	-	N/A	-
2.31. Spent shale for clinker production (coal and raw meals substitute)	QER	CA	-	N/A	Needs special investigation and trials
2.32. Shale ash (from oil shale/ spent shale burning)	QER	CA	-	N/A	Will need additional tests and feasibility study. Shale ash has similar properties to coal fly ash, and low transportation costs to deliver it from QER to CA
2.33. Spent shale/ shale ash/ waste rock as road base filling/ aggregate	QER	different customers	-	N/A	Needs special investigation and trials
2.34. Hydrogen sulphide	QER	GPNL	-	N/A	Will need additional feasibility study. The GPNL project is currently delayed
2.35. Ammonia supply	QER	GPNL/ Orica	-	N/A	Will need additional feasibility study. The GPNL and QER's full-scale projects are delayed
2.36. Sulphuric acid supply	GPNL/ QER	Orica	-	N/A	The GPNL project is delayed
2.37. Spent sulphuric acid recycling	Orica	GPNL/ QER	-	N/A	Currently recycled at Orica's facility in Port Kembla (NSW)
2.38. Barren liquor form GPNL can be reused for red mud co-neutralisation (instead of sea water), with the return of sodium-rich magnesium-depleted liquour back to GPNL to make a slurry suitable for HPAL processing	GPNL	RTA/ QAL	-	N/A	The GPNL project is delayed
2.39. Laterite nickel leached residue for iron recovery	GPNL	Boulder steel	-	N/A	Will need additional feasibility study. The GPNL and Boulder Steel projects are delayed
2.40. Met coke dust and fines as a fuel material	BSL	Boulder steel	-	N/A	Different types of dust are typically can be reused at a steel plant for iron recovery and as fuel substitutes. The Boulder Steel project is currently delayed
2.41. Granulated blast furnace slag	Boulder steel	CA	-	N/A	The Boulder Steel project is currently delayed

Suggested/existing synergy	From	To	2004 status	2012 status	Notes
2.42. Basic oxygen furnace steel slag (BOFS)	Boulder steel	CA	-	N/A	BOFS is preferably used as an aggregate material, but maybe also suitable for clinker/cement production
III. Other resource synergies (inter-regional exchanges)					
3.1. Fertiliser solution (ammonium nitrate)	Orica	Agricultural companies	In use	In use	The demand is seasonal
3.2. Alternative fuel materials: solvent-based fuels	Geocycle	CA	In use	In use	Geocycle Pty Ltd is a part of the Cement Australia Group