Industrial Symbiosis in the Australian Minerals Industry

The Cases of Kwinana and Gladstone

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Keywords

by-product synergy
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Summary

The realization of regional synergies in industrial areas with intensive minerals processing provides a significant avenue toward sustainable resource processing. This article provides an overview of past and current synergy developments in two of Australia's major heavy industrial regions, Kwinana (Western Australia) and Gladstone (Queensland), and includes a comparative review and assessment of the drivers, barriers, and trigger events for regional synergies initiatives in both areas. Kwinana and Gladstone compare favorably with well-known international examples in terms of the current level and maturity of industry involvement and collaboration and the commitment to further explore regional resource synergies. Kwinana stands out with regard to the number, diversity, complexity, and maturity of existing synergies. Gladstone is remarkable with regard to unusually large geographic boundaries and high dominance of one industry sector. Many diverse regional synergy opportunities still appear to exist in both industrial regions (particularly in Kwinana), mostly in three broad areas: water, energy, and inorganic by-product reuse. To enhance the further development of new regional synergies, the Centre for Sustainable Resource Processing (CSRP), a joint initiative of Australian minerals processing companies, research providers, and government agencies, has undertaken several collaborative projects. These include research to facilitate the process of identifying and evaluating potential synergy opportunities and assistance for the industries with feasibility studies and implementation of selected synergy projects in both regions. The article also reports on the progress to date from this CSRP research.

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Introduction

Australia is unique among industrialized economies for its degree of dependence on the mining and minerals sector. The direct contribution of minerals to GDP was around 9% during the 1990s and has increased since then. In 2000, Australia was among the top three producers for ten of the world's most important minerals, and exports account for over 80% of production (Sheeny and Dickie 2002). Australia's mineral endowments are diverse, extensive, and widespread over the country. Processing of the minerals typically involves beneficiation (grinding and removal of gangue[1]) and extractive metallurgy [extraction of the mineral or metal from the ore, most often through combinations of high temperature processing (pyrometallurgy, in smelters) and chemical leaching (hydrometallurgy)]. Processing takes place in Australia at or near the mine site (for instance, for gold and base metals) and/or in heavy industrial complexes (for instance, for bauxite and mineral sands). Over the last two to three decades, mining and minerals processing companies have progressed from resistant adaptation to environmental standards through compliance and beyond-compliance initiatives where such offer competitive advantage.

Minerals processing and metal production are associated with significant releases of liquid or solid wastes and gaseous emissions resulting from the chemical transformation steps that are necessary to smelt and refine the metals from the extracted ores. The intensive use of reagents, water, and fuels in primary metal production contributes to the generation of wastes. Sustainable minerals processing is concerned with finding ways to progressively and systematically eliminate wastes and emissions in the minerals cycle, while at the same time enhancing business performance and meeting community expectations (Herbertson and Sutton 2002; van Berkel and Narayanaswamy 2004). One way to reduce disposal of wastes or emissions to water and atmosphere is through the realization of regional resource synergies. These concern the capture, recovery, and reuse of previously discarded by-products from one industrial operation by other, traditionally separate, industries operating in their close proximity, a process most commonly referred to as industrial symbiosis (Chertow 2000). These can extend into utility synergies, the shared use of utility infrastructure, for example for energy production, water, and wastewater treatment (Altham and van Berkel 2004). In general, the terms "industrial symbiosis" and "regional synergies" can be used interchangeably. It can be argued, though, that the term "regional resource synergies" has a wider scope, as it also includes the shared use of utility infrastructure and industries that are not located in close proximity. The authors recognize that there is no standardized and internationally accepted methodology for defining and classifying industrial symbiosis and regional resource synergies. The field of industrial ecology would benefit from such an initiative; however, this exercise is not part of this article.

The Centre for Sustainable Resource Processing (CSRP) has recognized the important contribution regional synergies can make toward sustainable minerals processing. The CSRP is a joint initiative of Australian minerals processing companies, research providers, and state and local government agencies established under the Commonwealth Cooperative Research Centres Program, aimed at establishing a science and technology platform for the minerals processing industry to contribute to sustainable development (see <www.csrp.com.au>). The CSRP now undertakes foundational research into enabling tools and technologies for regional synergies and supports their further development and implementation in two Australian regions. The Kwinana Industrial Area is located in Western Australia, about 40 kilometers (km)[2] south of Perth, whereas the Gladstone Industrial Region is located in Queensland, approximately 550 km north of Brisbane. The current regional case study research has connected the synergy developments that previously took place in relative isolation.

The research is now aimed at documenting existing synergies and supporting the development and implementation of new synergies through assessment of resource inputs and outputs and identification and evaluation of synergy opportunities. This article summarizes and reviews past and ongoing regional synergy developments in Kwinana and Gladstone and includes a comparative review and assessment of the drivers, barriers, and trigger events for regional synergy initiatives in these two areas. Throughout this article, the term "by-product synergies" is used to refer to exchanges of by-products between industrial operations and the term "utility synergies" is used to refer to shared infrastructure, utilities, and exchanges of water and energy. Traditional supply chain synergies are not addressed in this article, because such supply synergies are business as usual where a business realizes a benefit from co-location with its main customers, a phenomenon well known as agglomeration economy (Desrochers 2004). These supply synergies therefore do not meet the criterion of "resource exchange between traditionally separate industries" as the distinctive feature of industrial symbiosis (Chertow 2000). Once matured, though, utility and by-product synergies de facto become new supply synergies.

Regional Synergy Developments in Kwinana, Western Australia

Kwinana Industrial Area

Western Australia is the largest and most sparsely populated state in Australia. The state has rich endowments of natural resources, including—but not limited to—iron ore, bauxite, gold, nickel, mineral sands, diamonds, natural gas, oil, and coal. Heavy process industry is concentrated in a few industrial areas, of which the Kwinana Industrial Area is by far the largest and most diverse. The industrial area was established in the 1950s following a special Act of Parliament, which secured an area of about 120 square kilometers (km^2) to accommodate the development of major resource processing industries in Western Australia. Kwinana is located 40 km south of the capital city of Perth on the shores of the Cockburn Sound, a sensitive marine environment. It has a deep water port and is therefore strategically placed for export markets in Asia. About 3,600 people work in the area's core industries, and many more in related sectors and service jobs. The total economic output of the area exceeds A$4.3 billion[3] annually (SKM 2002). Overall, the Kwinana Industrial Area plays a very important role in the economy of Western Australia and in the local community. The region has long been recognized as a cornerstone of Western Australia's economy.

The Kwinana Industrial Area is dominated by heavy process industries. These include (SKM 2002) a 2,000 kilotonne-(kt)[4]/yr alumina refinery (Alcoa), a 70-kt/yr nickel refinery (Kwinana Nickel Refinery), a 105-kt/yr titanium dioxide pigment plant (Tiwest), 850-kt/yr lime and cement kilns (Cockburn Cement), a 135,000-barrel/day oil refinery (BP), and an 800-kt/yr pig iron plant (HIsmelt). These are complemented by a variety of chemical producers, including CSBP (ammonia, ammonia nitrate, cyanide, chlor-alkali, and fertilizer plants), Coogee Chemicals (inorganic chemicals), Nufarm (herbicides and other agricultural chemicals), Nufarm Coogee (a chlor-alkali plant), Bayer (agricultural chemicals), Chemeq (veterinary products), and Ciba and Nalco (water treatment and process chemicals). Moreover, there are important utility operations, including two power stations (900-MW coal-, oil-, and gas-fired and 240-MW combined cycle gas) both owned by Verve Energy, two cogeneration plants [respectively 116 MW (Kwinana Cogeneration Plant) and 40 MW (Verve Energy)], two air separation plants (Air Liquide and BOC Gases), a grain handling and export terminal (CBH), port facilities (Fremantle Port Authority), and water and wastewater treatment plants (Water Corporation). Historically considerable supply chain integration has occurred between these industries in the area. A number of companies produce essential raw materials for the manufacturing and refining processes of other nearby enterprises. Figure 1 provides an overview of the locations of companies in Kwinana.

In 1991 the core industries established the Kwinana Industries Council (KIC; see <www.kic.org.au>). Until then there was no formal industry association for the Kwinana Industrial Area. The original purpose of the KIC was to organize the required air and water monitoring collectively for the industries in the area. This was in response to increased government and community pressure to manage the air- and watersheds and protect the sensitive marine environment in the adjacent Cockburn Sound. The KIC now addresses a broad range of issues common to Kwinana's major industries, and seeks

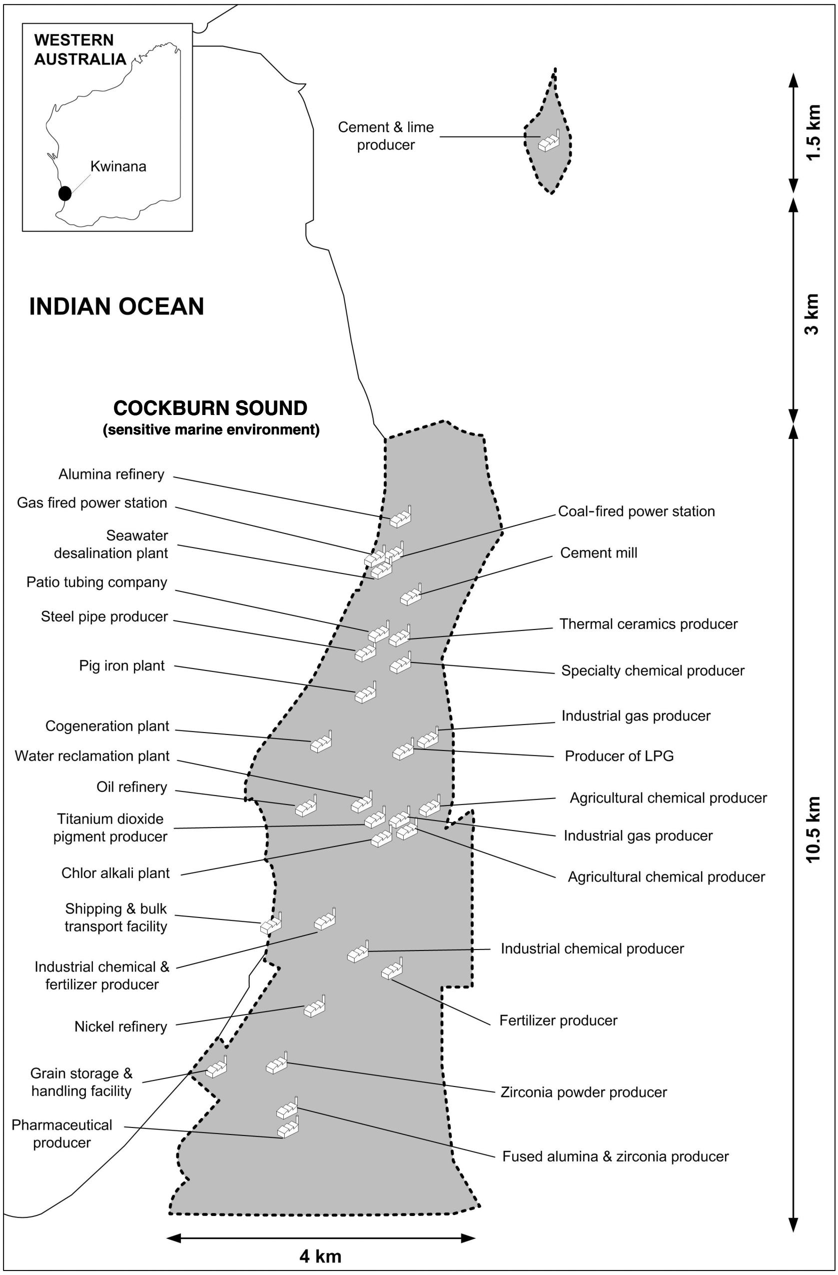

Figure 1 Location of companies in Kwinana Industrial Area in Western Australia. The grey colored area represents the Kwinana Industrial Area.

to foster positive interactions between member companies, government, and the broader community.

Based on the desire of the local industries and the state government to understand and document the full economic and social contributions of the Kwinana Industrial Area, the KIC initiated regional economic impact studies, which included an analysis of the principal material and energy flows within the area and also assessed the level of industrial integration. The most recent study was conducted in 2001 (SKM 2002) and

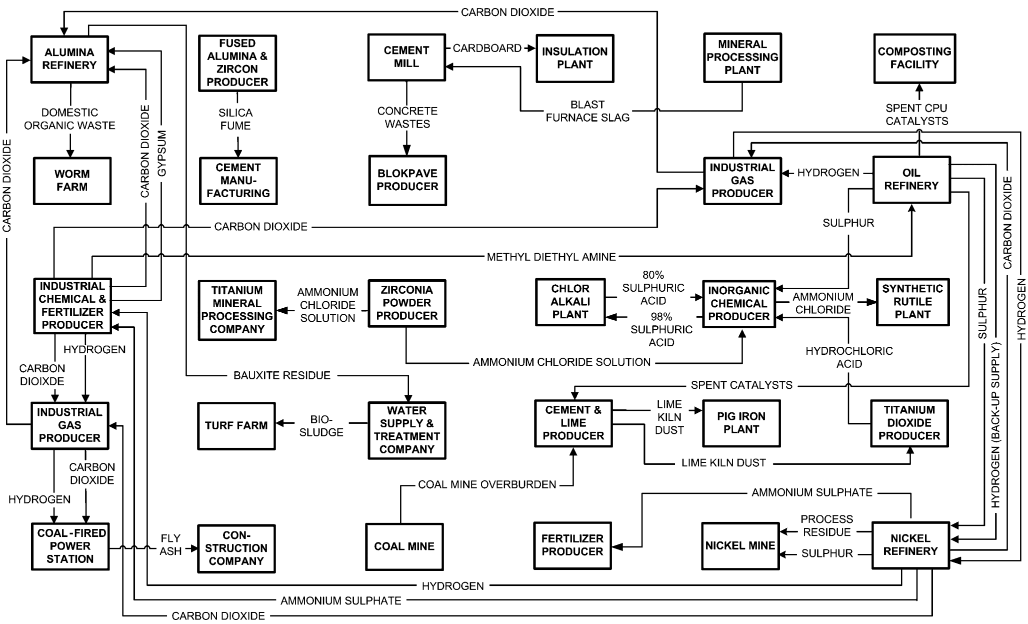

Figure 2 Existing by-product synergies in Kwinana. Figure includes only the Kwinana industries (both members and non-members of the Kwinana Industry Council, KIC) that are involved in regional synergies. *Source:* van Beers and colleagues (2005).

used the findings of a similar study undertaken earlier (Dames and Moore 1990) to compare and illustrate the growing complexity of industrial interrelation over a ten-year period. As part of its findings this study revealed that between 1990 and 2000, the number of core process industries in Kwinana increased from 13 to 21, and the number of existing interactions increased from 27 to 106 (including 68 between core process industries and 38 with service and infrastructure industries). Each interaction represents either transfer of product(s), transfer of by-products, or commercial cooperation. Based on a preliminary review of material and energy flows in the area, another 55 possible interactions were identified, but their technical and economic feasibility was not assessed in detail (Altham and van Berkel 2004).

Upon completion of the second economic impact study (SKM 2002), the KIC initiated the Kwinana Industries Synergies Project (Taylor 2002). This later merged with the activities of the Centre of Excellence in Cleaner Production at the Curtin University of Technology (as a core participant in the Centre for Sustainable Resource Processing) because of the center's strong industrial focus and connections with a number of key Kwinana industries. Opportunities have since been pursued by the KIC in four areas: large volume inorganic process residues (e.g., fly ash, bauxite residue, gypsum), nonprocess waste (e.g. collection and recycling of dry recyclables), energy and greenhouse gas emissions (reuse of low grade heat and sharing of energy efficiency practices among Kwinana companies), and water conservation.

Current Regional Synergies

The recently updated inventory of existing synergies (van Beers et al. 2005) showed that these are quite diverse in Kwinana. Forty-seven synergy projects are in place, including 32 by-product synergies (figure 2) and 15 utility synergies (figure 3). The inventory was compiled from industry surveys and is therefore not necessarily complete. Each synergy can involve multiple material, water, and/or energy flows. This is, for

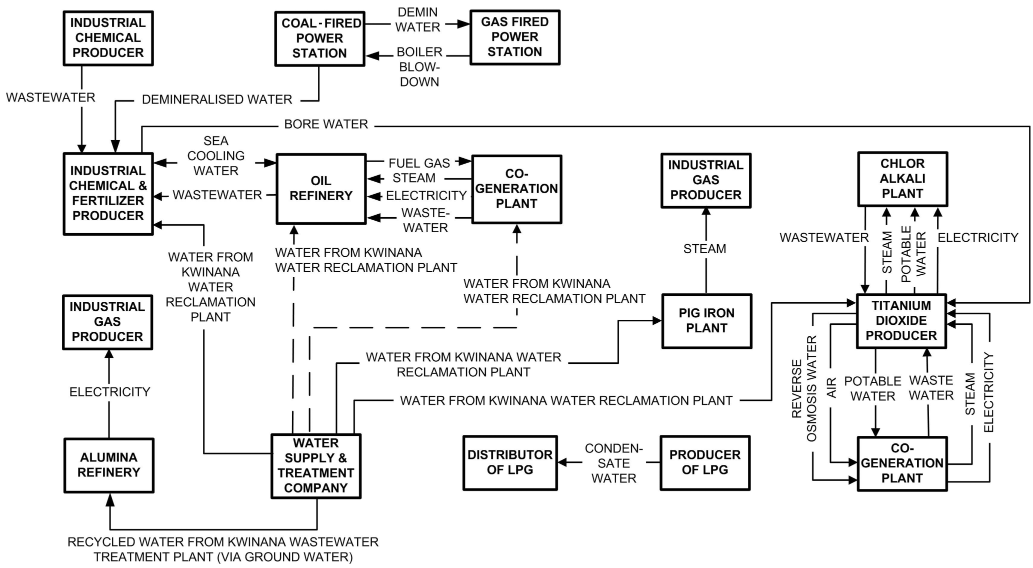

Figure 3 Existing utility synergies in Kwinana. Figure only includes the Kwinana industries (both members and nonmembers of the Kwinana Industry Council, KIC) that are involved in regional synergies. *Source:* van Beers and colleagues (2005).

example, the case when a by-product is being returned (e.g., in a processed form) to the producer, or forwarded to another company for further processing.

Some illustrative by-product and utility synergies are described here.

By-product Synergy

The CSBP chemical works supplies gypsum for residue area amelioration at the alumina refinery. CSBP produced gypsum (i.e., calcium sulfate) as a by-product of the manufacture of phosphoric acid. Even though this practice ended in the 1980s, there remains a stockpile of some 1.3 million tonnes of gypsum. CSBP has extensively reviewed reuse options for this material, including use in plasterboard, sale to farmers, and use for soil amendment. It was found that the material could be utilized by the Alcoa alumina refinery to assist in plant growth and soil stability in its residue areas. Alcoa takes this material on an ongoing basis, approximately 10,000 tonnes each year. This project is beneficial for both parties, including lower gypsum cost for Alcoa and a reduction of liabilities associated with the gypsum stockpile for CSBP.

Utility Synergy

Built in 1999, a cogeneration facility (40 MW), owned by Verve Energy, provides superheated steam and electricity for the process needs at the Tiwest pigment plant. Tiwest has the ability to "island," taking electricity directly from the cogeneration plant. For the majority of the time, however, the cogeneration plant feeds the grid with Tiwest drawing power from the grid. The cogeneration plant gets its water (potable and demineralized) and pressurized air from the pigment plant, and the facility returns its wastewater to Tiwest's wastewater treatment plant.

Treated wastewater from the Water Corporation's Kwinana Waste Water Treatment Plant (WWTP) is infiltrated into groundwater upstream from the groundwater extraction bores of the Alcoa alumina refinery. The bores supply water for Alcoa's process water circuit for the Kwinana alumina refinery. Thus the discharge from Kwinana WWTP is indirectly reused by the alumina refinery and is estimated at 1.1 gigaliter (GL) per annum.[5]

Unique Features of Kwinana

A number of factors are unique to Kwinana and these have without doubt contributed to regional synergy developments in the area. These include the following:

- the diverse blend of key processing and manufacturing industries primarily producing for international markets with limited local competition between companies operating in the area
- the relative isolation from other major industrial centers in Eastern Australia and internationally
- a member-based industry organization (Kwinana Industries Council) that addresses a broad range of issues common to the industries in the area
- the vicinity to Perth as a major metropolitan center
- the gradual urban encroachment around the industrial area
- the growing recognition of the natural resource value of the Cockburn Sound on whose shore the Kwinana Industrial Area is located

Key industries and the Kwinana Industries Council have made it a strategic priority to move toward the next level of resource synergies in Kwinana.

New Regional Synergy Opportunities

Two major new industrial facilities that further enhance regional synergy developments have been constructed and are progressively being commissioned since November 2004:

The world's first commercial 800,000 tonne/yr direct reduction iron-making plant (HIsmelt). This technology provides a simpler and more flexible iron-making route that avoids the use of coke ovens and sinter plants from the standard blast furnace production route. The environmental benefits for this new technology will be 20% reduction of carbon dioxide (CO_2), 40% reduction of nitrogen oxides (NO_x), and 90% reduction of sulfur oxides (SO_x) compared to blast furnace steel production. Upon completion of commissioning and successful commercial operation, the plant will be able to source a number of inputs locally, such as lime, lime kiln dust, and treated wastewater, and provide outputs with potential for local reuse, such as slag and gypsum. The HIsmelt process will utilize Western Australia's reserves of iron ore fines, which are currently not suitable for blast furnace feed due to their high phosphorous content (HIsmelt 2002).

A water reclamation plant that produces 6 GL/yr premium quality industrial process water from tertiary treated wastewater. The Kwinana Water Reclamation Plant (KWRP) is a joint initiative of the water utility company (Water Corporation) and the Kwinana industries (e.g., pig iron plant, industrial chemical producer, pigment plant, oil refinery, and cogeneration plant) and achieves the double benefit of greater overall water efficiency and reduced industrial wastewater discharges into a sensitive marine environment (Cockburn Sound). The low TDS level (total dissolved solids) enables the process plants to cut chemicals use in cooling towers and other process applications, which reduces metal loads in their effluents. In exchange for taking water from the water reclamation plant, the industries will be able to discharge their treated effluents into the deep ocean outfall (about 4 km off the coast) through the pipeline of the water utility company, thereby eliminating process water discharges to the sensitive coastal area (Water Corporation 2003).

The dynamic nature of industry developments in the area implies that current synergies might cease to exist in the future as businesses improve their own processes (through eco-efficiency and eco-innovation) or decide to relocate. On the other hand, new opportunities will emerge with the establishment of new industries in the area, as has been so vividly illustrated with the recent establishment of the HIsmelt iron-making plant.

Despite the growing number of regional synergies, it appears that only direct reuse opportunities available through relatively well established technologies (e.g., heat exchange, water reuse, and cogeneration) have been realized. This implies that even though Kwinana is well positioned as an example of international best practice in regional synergies, technology and engineering challenges have prevented many other potential opportunities from being realized. The CSRP regional synergy research in Kwinana assists companies with the realization of further synergies. As of yet, over 90 synergy opportunities have been identified through four activities: a resource and process flow database, focused opportunity identification workshops, on-site company visits, and a review of earlier reports on synergies in Kwinana (e.g., [SKM 2002]). A preliminary screening exercise was conducted to eliminate those synergies that could readily be identified as unfeasible or without significant sustainability benefits (e.g., only very small quantities of materials are involved). As a result, the synergy opportunities were consolidated into a list of 25 priority projects for consideration by the KIC (list available in report by van Beers et al. [2005]). Based on the interest and perceived importance by the KIC and the industries, current development efforts focus on nine short-listed priorities, with regard to water (e.g., reuse of treated industrial effluents, demineralized water, and treatment of oily wastewater) and by-products (e.g., recovery and reuse of sodium sulfate, ammonium sulfate, graphite electrodes, grain dust, and zirconia process waste) (van Beers 2006). The feasibility assessments of these potential synergies comprise detailed evaluations of the by-product streams (volumes and composition), reviews of potential uses, evaluations of possible processing and source treatment needs, concept designs, and assessments of the economic, technical, environmental, and social aspects. In addition to the hands-on support to these short-term synergy opportunities, the research contributes to the development of collective strategies for the Kwinana region on the recovery and reuse of inorganic by-products, water, and energy. These efforts have a more long-term and strategic focus and are conducted in close cooperation with the Kwinana Industries Council.

Regional Synergy Developments in Gladstone, Queensland

Gladstone Industrial Area

Queensland is Australia's second largest state in terms of both size and mineral resources reserves. Gladstone is situated some 550 km north of Queensland's capital, Brisbane. It is one of the most industrially intensive areas in Australia and generates 30% of Queensland's and 10% of Australia's total volume of exports, valued at over $A4 billion annually. Although major industrial operations have been part of this region since Queensland Alumina Limited commenced operation in 1967, a 21,000-hectare (ha)[6] industrial land bank, known as the Gladstone State Development Area, was established in 1993 to secure a large area of suitable land for major industrial development over a 30- to 50-year timeframe (GEIDB 2005). Gladstone has ready access to a deep-water port as well as a worldclass road and rail transport infrastructure.

Today several major industries operate in the region and form an association called the Gladstone Area Industry Network (GAIN). GAIN comprises a 3,700-kt/yr alumina refinery (Queensland Alumina), a 1,680-MW coal-fired power station (NRG), a 1,500-kt/yr cement clinker plant (Cement Australia), a 540-kt/yr aluminum smelter (Boyne Smelters), a 600-kt/yr ammonium nitrate (upon completion of current expansion in 2006) plus 60-kt/yr sodium cyanide and 9-kt/yr chlorine plant (Orica), a 1,400-kt/yr (when fully commissioned) alumina refinery (Comalco Alumina Refinery), the largest Queensland multicargo port, exporting over 43,000 kt/yr of coal (Central Queensland Ports Authority), the Awoonga Dam (Gladstone Area Water Board), and a proposed shale oil mine and processing plant (Queensland Energy Resources). Apart from the utility suppliers, the major value-chain integration is the supply of alumina from Queensland Alumina to Boyne Aluminium Smelters. Several smaller companies also support the major industries.

Figure 4 shows the location of the main process industries in Gladstone.

Current Regional Synergies

Currently, there are five main current synergies in Gladstone (Corder 2005):

1. *Alternative fuels for cement clinker production*: Cement Australia is voluntarily committed to use alternative fuels, for environmental, economic, and social reasons. Wastes and by-products with high calorific value are used as a substitute for part of the coal used to fuel the kilns. Operating at high temperatures (1500 to 1800°C) and

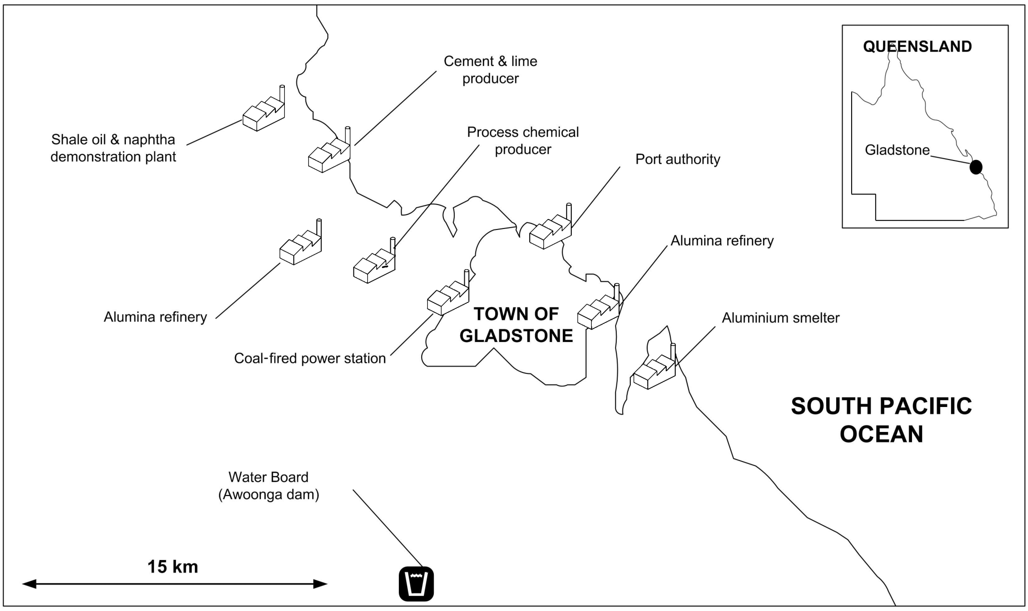

Figure 4 Location of companies in Gladstone Industrial Area (Queensland).

with long residence times (4 to 6 sec) allows cement kilns to destroy wastes and by-products while extracting the calorific heating value. The Gladstone operation uses

a. domestic tires, which have typically been disposed to landfill
b. solvent-based fuels, prepared from hazardous and combustible wastes
c. spent cell linings from the Boyne Aluminium Smelter (this is a waste generated in the reduction of alumina to aluminum and contains silica, alumina, and fluoride, which benefit the process of manufacturing cement)

2. *Water reuse*: In 2002, Gladstone suffered one of the worst droughts ever known in the region. The seriousness of the drought resulted initially in 10% water restrictions followed by additional 15% water restrictions some 6 months later. Queensland Alumina could accommodate the initial 10% water restrictions but would have been faced with significant production losses if forced to operate with a total of 25% less water than usual. Queensland Alumina decided to fund a project to build an 8.5-km pipeline so that secondary treated effluent from the Calliope River Sewage Treatment Plant could be used for its mud-washing process. This scheme not only resulted in a water savings for Queensland Alumina of about 6.5 ML/day but also ended the discharge of treated effluent from the Calliope River Sewage Treatment Plant into the local waterway and eliminated the need for the treatment facility to upgrade to tertiary treatment in the future (Australian Aluminium Council 2004).
3. *Waste separation and reuse*: Transpacific Industries established a waste sorting and transfer facility at Queensland Alumina in June 2003. The main incentive for this facility was to divert waste from landfill. Most of Queensland Alumina's waste streams, apart from old asbestos waste, bauxite residue, and fly ash, are now sorted for reuse, recycling, or reselling. After 6 months of operation, Queensland Alumina reported the total elimination of waste going to the company's landfill. The reported recycle rate was about 85% of wastes, mostly from metal, cardboard, and wood, and the facility was cost-neutral

(QAL 2004a). Most of the recovery costs are recouped from the reselling of scrap metal. After 12 months of operation, the recycle rate had passed 90% (QAL 2004b).

4. *Fly ash reuse*: Pozzolanic Enterprises, a subsidiary of Cement Australia, collects fly ash from the Gladstone power station for use as a cement additive in Cement Australia operations. Fly ash has chemical and physical properties, in particular its sphericity and fine size, that are beneficial in concrete production. Pozzolanic selects fly ash that meets the required specifications, with the remaining fly ash being discharged to local ash dams (impoundment). The power station benefits from a reduction in fly ash disposal. The cement operations benefit from improved product quality as well as reduced use of conventional raw materials.
5. *Caustic recovery*: At Boyne Aluminium Smelters, by-product caustic soda (sodium hydroxide) is produced from the treatment of spent cell linings to remove leachable fluorides and cyanides. The recovered caustic soda is used at the nearby Queensland Alumina refinery as a supplementary source of caustic soda. It represents only a small percentage of the total caustic soda use.

The above-mentioned synergies have sound commercial benefits. The alternative fuel strategy reduces costs associated with traditional fuel sources, the effluent reuse scheme prevented production losses during water restrictions, the waste transfer facility is less costly than landfill, the reuse of fly ash reduces cement raw material costs and produces a superior product, and the by-product caustic soda provides a local supplementary source. In addition, beyond the solid economic basis, these synergies also show substantial environmental and community benefits.

A schematic overview of the current synergies in Gladstone is presented in figure 5.

New Regional Synergy Opportunities

The CSRP research in Gladstone assists operations to achieve greater efficiencies in energy, water, and materials consumption and reductions in waste and emission generation. A database of material, energy, and water inputs and by-product generation from the principal companies was established (Corder 2005). Additional interviews with the GAIN industries and independent research resulted in a list of both short- and long-term opportunities. All these opportunities were reviewed at a workshop with industry and state/local governments with the purpose of selecting synergy projects with the perceived best business and sustainability case for the involved companies and the region as a whole.

Two short-term projects are being assessed for feasibility, respectively the consolidation of wastes for use as an alternative fuel source for cement clinker manufacturing and the (re-)use of "fit-for-purpose" water. The alternative fuels synergy requires a central facility to collect and blend low-volume wastes so that a sizeable and consistent alternative fuel source is available for cement manufacturing. This would divert wastes from landfill, while also providing Cement Australia (and potentially other industries) with an alternative fuel. Several possibilities for water reuse are conceivable, for example, reuse of treated effluent from sewage treatment plants and industrial wastewater as process water in nearby industries.

As long-term projects, opportunities should be assessed for the recovery and reuse of large-volume waste streams (bauxite residue and fly ash) and gaseous emissions (carbon dioxide and sulfur dioxide). Moreover, there is the potential to improve process energy utilization (e.g., waste heat) in the Gladstone industrial area. The current research in Gladstone is monitoring the technological developments related to the selected long-term synergies and documenting those that are specifically appropriate to the Gladstone industrial region.

Comparative Analysis

As apparent from previous sections, both Kwinana and Gladstone are unique in their industry mix, geography, and organizational set-up. Table 1 summarizes key features of both areas. Kwinana has a diverse blend of key processing and manufacturing industries primarily producing for international markets with limited local competition. Its ownership is diversified,

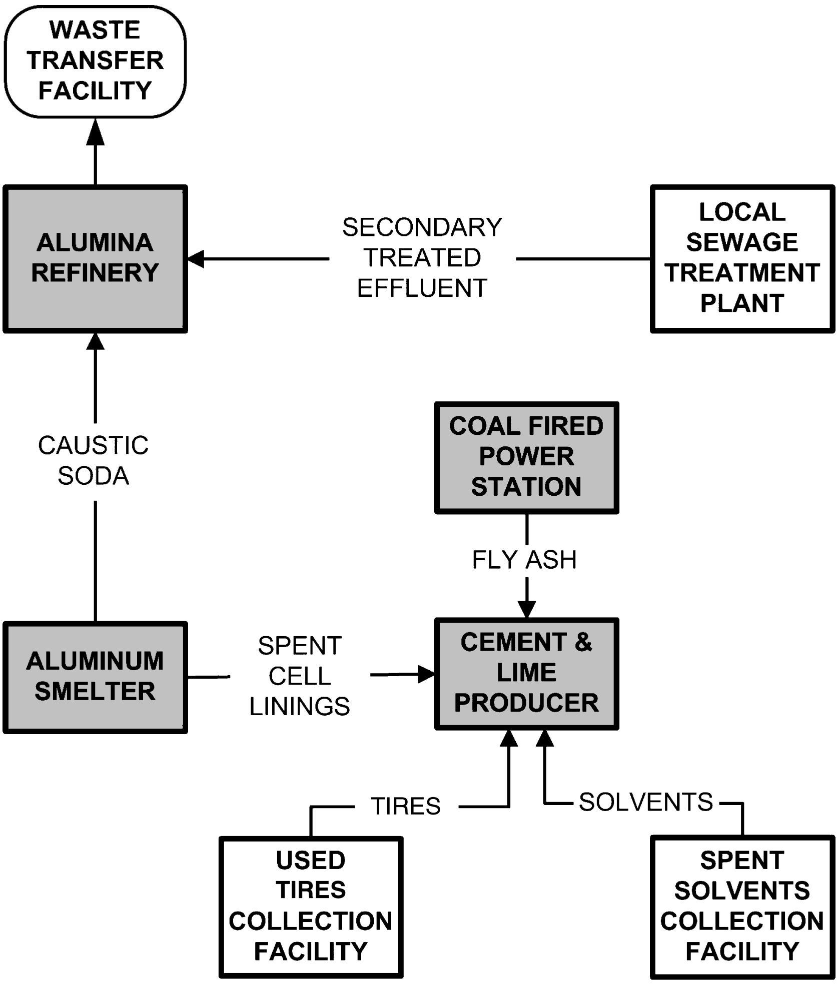

Figure 5 Existing by-product and utility synergies in Gladstone (Corder 2005). Shaded boxes indicate companies that are members of the Gladstone Area Industry Network (GAIN); unshaded boxes represent companies that are not members of GAIN.

including Australian companies (e.g., CSBP, Coogee, Cockburn Cement, Verve Energy, Water Corporation), joint ventures (e.g., Tiwest, Nufarm-Coogee, HIsmelt), and subsidiaries of multinational companies (e.g., Alcoa, BP, BHP Billiton). Gladstone is dominated by aluminum-related operations supported by utility industries (e.g., energy, water, port facilities). Rio Tinto Aluminum owns and operates one of the six key processing companies and has a share in the ownership of three of the other industries (power station, aluminum smelter, and alumina refinery). Kwinana accommodates 15 major process industries in an 8 × 2 km coastal strip, whereas industries in Gladstone are fewer (6 major processing industries) and located further apart (in a regional center with a radius of approximately 20 km). Overall Kwinana and Gladstone both compare favorably with the renowned international examples of regional synergy development (e.g., Kalundborg, Rotterdam), in terms of the level and maturity of the industry involvement and collaboration, and the commitment to future regional resource synergies. Specifically, Kwinana stands out with regard to the number, diversity, complexity, and maturity of existing synergies. Gladstone is remarkable as it stands out as an example with unusually large

Table 1 Comparative review of Kwinana and Gladstone

	Kwinana	*Gladstone*
	GENERAL	
Number of major industries[a]	15	6
Key sectors	Alumina, nickel, iron, oil refinery, pigment, cement, chemicals, fertilizers, power generation, water supply and treatment	Alumina and aluminum, cement, chemicals, power generation, oil shale, major port, and water supply and treatment
Location	~40 km south of Perth	~550 km north of Brisbane
Area	Coastal strip of ~8 × 2 km	Regional center with radius of ~20 km
Ownership	Diversified national and international ownership	Ownership dominated by Rio Tinto Aluminum (Australia/New Zealand/UK)
Industry organization	Kwinana Industries Council (KIC), established in 1991, currently 37 paying members	Gladstone Area Industry Network, established in 1996, 9 members
	EXISTING SYNERGIES[b]	
Total regional synergies	47	5
• Existing by-product synergies	32	4
• Existing utility synergies	15	1
Number of local companies involved in synergies (located in industrial region)	22	6
Number of "external" companies involved in synergies (located outside industrial region)	13	1
	POTENTIAL SYNERGIES	
Approach to identifying new synergies	Step-by-step methodology based on cleaner production approach (planning and organization, preliminary assessment, assessment, feasibility studies, implementation and continuation)	
Current focus areas	Water efficiency, waste energy, nonprocess organic by-products, process inorganic by-products	Energy from wastes and alternative fuels, water efficiency

[a] *Note*: Major industries are those companies that have comparatively larger process facilities than other companies within the industrial region, excluding small and medium-sized enterprises.
[b] Details on these synergies can be found in figures 2, 3, and 5.
Source: Corder et al. 2006.

geographic boundaries and unusually high dominance of one industry sector (alumina and aluminum and its power supplier) (Bossilkov et al. 2005).

Valuable lessons can be learned from regional synergy experiences in Kwinana and Gladstone. Table 2 includes a selection of the main drivers, barriers, and triggers for these synergy developments. Although not all drivers, barriers, and trigger events listed in table 2 can be discussed in detail in this article, some specific examples from Kwinana and Gladstone are provided below to illustrate each of the main categories referred to in the table.

Table 2 Drivers, barriers, and triggers for regional synergies, based on Kwinana and Gladstone

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

Economics

Operational costs and revenue function as important synergy drivers. Most synergy projects make good business sense, through a combination of lower input costs, lower operational costs, and/or increased revenues. The recovery and reuse of hydrochloric acid at the Tiwest pigment plant combines all three. Dilute hydrochloric acid is generated by scrubbing the gas stream in the chlorination step in the titanium dioxide pigment plant. The acid was previously neutralized in the waste treatment plant. In 1997 Tiwest installed a second scrubber to be able to run the first scrubber at higher acid concentrations, while maintaining the second scrubber at lower concentrations to maintain emissions standards. The weak hydrochloric acid from the first scrubber has become a valuable by-product. It is sold to Coogee Chemicals to produce ammonium chloride, which it then tankers for use in Tiwest's synthetic rutile plant some 75 km from the Kwinana refinery. The cost of the ammonium chloride to the synthetic rutile plant is significantly less than that previously imported, whereas wastewater costs have been reduced and revenues increased at the pigment plant (DEH 2001).

Resource scarcity also acts as an economic trigger. A number of utility synergies have come to fruition because of concerns for continued access to a vital resource for running the business. An acute example, as described above, was the drought in Gladstone, which triggered the investment in a pipeline to use secondary treated effluent for mud washing at Queensland Alumina. Likewise in Kwinana the water reclamation plant was built to accommodate the establishment of HIsmelt, which could not get access to another source of process water.

Information Availability

Local and regional studies operated as a trigger for synergy development. Although some synergies were happening, it took an external study to review and document regional resource flows and synergy opportunities to trigger broader industry interest and commitment for regional synergies. In Kwinana, the regional economic impact study (SKM 2002) was coordinated by the Kwinana Industries Council and financially supported by the Commonwealth and state government. It revealed the exponential growth in industry integration in the area over the 1990s and suggested that many more exchanges would in principle be possible. The discussions in the project steering group for this study lead to the direct realization of some synergies, such as the reuse of waste gypsum from CSBP by the Alcoa bauxite residue operation. In Gladstone, several attempts were made to assess the sustainability of the region, before a by-product mapping study was conducted (GAPD 2001), which then caught the imagination of industry and regional development authorities.

Another driver for synergy development has been staff mobility. Mobility of staff between neighboring operations has contributed to synergies in two different ways. In the case of staff mobility between similar industries, such as the two Gladstone alumina refineries, staff mobility has resulted in a wider pool of knowledge. Provided there are no major confidentiality issues, the greater depth of expertise can lead to improved efficiency and performance at both operations. In the case of staff mobility between different industries, for example in Kwinana, it has led to a greater awareness of industrial operations and their associated process inputs and outputs, which has contributed significantly to identifying synergy opportunities.

Corporate Citizenship and Business Strategy

Kwinana, and to a lesser extent also Gladstone, are increasingly subject to urban encroachment and resulting higher community expectations with regard to environmental and safety performance and overall amenity. Kwinana is located on the shore of the Cockburn Sound, a sensitive marine environment and recreational area for local residents. The opportunity to transfer the discharge of treated process wastewater from the coastal area into the deep ocean outlet as part of the Kwinana Water Reclamation Plant (KWRP) was therefore an important consideration for CSBP, Tiwest, and BP to purchase the higher-cost water from KWRP. Moreover, the CSBP chemical and fertilizer plant built in 2004 an innovative nutrient-stripping wetland to further reduce the nitrogen discharges to the adjacent Cockburn Sound. The pilot wetland was constructed on land leased from the BP refinery. The wetland is planted with sedges and incorporates a number of biological processes that will reduce the level of nitrogen in the CSBP's effluent stream. Some of BP's effluent is also released into the wetland and it is found to provide additional benefits by supplementing the carbon loading.

The core business focus of the participating industries sometimes functioned as a synergy barrier. In both Gladstone and Kwinana, the emphasis of site personnel is on core business activities, resulting in potential missed synergy opportunities unless there is an overwhelming commercial benefit. This is recognized by various site personnel, who see one of the main aims of the regional synergies research is to identify and progress synergy opportunities that are unrelated to the core business.

Region-Specific Issues

Major capital projects served as a synergy driver and trigger, particularly with respect to new operations or significant capacity expansion projects in existing operations. In Kwinana, two new industrial facilities were built and commissioned in 2004 (the Kwinana Water Reclamation Plant and the HIsmelt direct-reduction iron making plant). The HIsmelt plant is able to source a number of inputs locally in the Kwinana area, such as lime, lime kiln dust, and treated wastewater, and provide outputs with potential for reuse in Kwinana, such as slag and gypsum. HIsmelt triggered the undertaking of the Kwinana Water Reclamation Plant (KWRP), as the groundwater allocation for the area had already been licensed to the existing industries and there was limited availability of catchment (potable) water in the metropolitan area of Perth.

The distance between companies was a barrier to synergy development: As illustrated in figure 4, the distances between the major operations in the Gladstone region do not contribute to regional synergy developments. As an example, the spent cell linings from Boyne Aluminium Smelters have to travel via road about 40 km and through two local municipalities to Cement Australia for use as an alternative fuel. Although this is not a barrier in this case, it does make it more complicated than just transferring a by-product across a boundary fence to a neighboring operation. Even though Kwinana is more compact, the distances still pose a challenge with regard to, for example, recovery and reuse of process energy and water.

Regulation

Environmental regulations can be a barrier to regional synergy development. Kwinana companies are experiencing obstacles in getting governmental approvals for use of alternative fuels and raw materials. Although some by-product synergies appear technically and economically feasible and have a positive sustainability impact (e.g., alternative fuels in cement kilns and use of bauxite residue for soil conditioning), their practical implementation has been halted by uncertainties in the legislative framework, in particular with regard to the final responsibility for approved reuse options, and community concern. Additionally, if a by-product is classified as a controlled waste (for example, fly ash), strict transportation procedures and requirements apply.

Regulations could also be a trigger for regional synergies. Currently secondary treated effluent from sewage treatment plants in the Gladstone region is discharged to local waterways. As it is likely in the future that effluent must be tertiary treated before being discharged to local waterways, local councils and industries are investigating the potential of reusing tertiary treated effluent in industrial operations. Such schemes would reduce consumption of fresh (potable) water and offset the cost of installing tertiary treatment facilities (Corder 2005).

Technical Issues

Another synergy driver was the technical obsolescence of existing process equipment. The Kwinana Cogeneration Plant is located on land of the BP oil refinery, produces all process steam for the refinery, and generates electricity for BP as well as the grid. The cogeneration plant is fired with excess refinery gas from the oil refinery supplemented with natural gas. The cogeneration plant, built in 1996, took the place of the BP steam boilers, which were in need of replacement at the time. This synergy allowed BP to decommission its old inefficient boilers, estimated to have saved the refinery in the vicinity of A$15 million in capital expenditure, while ensuring a cost-competitive, reliable source of steam and electricity for their refinery. Moreover, the refinery has achieved greater refinery process efficiencies as a result of the greater and more flexible availability of high-pressure steam from the cogeneration facility.

Major brownfield expansion functioned as a synergy trigger as well. One of the synergy opportunities identified by the Gladstone synergies research was the use of return sea water from a bauxite residue neutralization process as cooling water, instead of fresh water, at the neighboring plant expansion. This return sea water is treated to meet ocean discharge requirements. As this opportunity was identified at a time when the expansion project was well under way, it was not practical due to various project constraints to develop this synergy. It does, however, illustrate that potential synergy opportunities should now be considered during the feasibility and design stage of a greenfield site or brownfield expansion.

Conclusions

The summary and review of regional synergy developments in Kwinana and Gladstone compare favorably with well-regarded international examples, for example Kalundborg (Denmark) and Rotterdam (The Netherlands) (Bossilkov et al. 2005). Local industries (particularly in Kwinana) have widespread enthusiasm and commitment to achieve greater regional synergies and thereby make a contribution to sustainable development in the area.

Many diverse regional synergy opportunities still appear to exist in both industrial regions, mostly in three broad areas: water efficiency and exchanges, energy efficiency and exchanges, and industrial inorganic by-product reuse. Current development efforts focus on conducting feasibility studies of prioritized synergy opportunities. The researchers in Kwinana and Gladstone work closely together with the local industries; the type and level of assistance to the development of new synergies depends entirely on the specific research needs of the involved companies. A number of tools and methodologies are being applied to assist with the identification and development of synergies, including a resource and process flow database, opportunity identification workshops with industries, and triple-bottom-line evaluation (van Berkel et al. 2006). A recent review of international case studies (van Berkel 2006) illustrated the importance of proven technology, a convincing business case, and a license to operate to develop a successful synergy project. Whatever benefits can be achieved through regional synergies, it is important that industries can justify any new synergy in terms of a sound business case (Corder et al. 2006). It is recognized by most industries that the business case for synergies does not depend solely on the financial benefits, but also is affected by other sustainability aspects, such as risk management, continued access to vital resources, environmental legislation, and community relations.

The assessment of drivers, barriers, and triggers for regional synergy development in Kwinana and Gladstone appear to fall into six broad categories: economics, information availability, organizational and social issues, region-specific issues, regulations, and technical issues. From this assessment, it is clear that a wide range of drivers and barriers exist, which are influenced by diverse sets of stakeholders (e.g., companies, regulators, community). In addition, trigger events played an important role in synergy developments in Kwinana and Gladstone. The assessment illustrates that the complete set of drivers, barriers, and trigger events, rather than one specific aspect, determine the business and sustainability case for a regional synergy opportunity and hence are key to the implementation of by-product or utility synergy projects. Overall, it is clear that there is no "one-size-fits-all" approach to developing regional synergies; each synergy is unique in terms of its drivers, barriers, business case, and sustainability benefits.

The enabling mechanisms for overcoming barriers and boosting incentives, as outlined in this article, play a very important role in the further development of regional synergies in both Kwinana and Gladstone. Foundational research at Curtin University of Technology, funded by the Australian Research Council (ARC) under its Linkage Program, will continue to address these synergy-enabling mechanisms, including a detailed investigation of the role of the regulator and a facilitator in assisting industries to implement synergies (van Berkel 2006).

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Notes

1. Gangue is the rock or other valueless material that surrounds the ore.
2. One kilometer (km, SI) ≈ 0.621 miles (mi).
3. As of October 2006, 1 Australian dollar (AUD) ≈ $.74 US dollars (USD) ≈ .59 € (EUR).
4. One kilotonne (kt) = 10^3 tonnes (t) = 10^3 megagrams (Mg, SI) ≈ 1.102 × 10^3 short tons.
5. One liter (L) = 0.001 cubic meters (m^3, SI) ≈ 0.264 gallons (gal).
6. One hectare (ha) = 0.01 square kilometers (km^2, SI) ≈ 0.00386 square miles ≈ 2.47 acres.

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