Regional synergies in the Australian minerals industry: Case-studies and enabling tools

D. van Beers a,b,*, G.D. Corder a,c, A. Bossilkov a,b, R. van Berkel a,d

a Centre for Sustainable Resource Processing, Curtin University of Technology, P.O. Box 1130, Bentley, WA 6102, Australia
b Centre of Excellence in Cleaner Production, Curtin University of Technology, G.P.O. Box U 1987, Perth, WA 6845, Australia
c Centre for Social Responsibility in Mining, Sustainable Minerals Institute, University of Queensland, St Lucia, QLD 4072, Australia
d CSIRO Minerals, P.O. Box 7229, Karawara, WA 6152, Australia

Received 23 November 2006; accepted 2 April 2007
Available online 25 May 2007

Abstract

Regional resource synergies (exchanges of by-products, water and energy between companies) in areas with concentrations of minerals processing provide a significant avenue towards sustainable resource processing. Since 2003, the Centre for Sustainable Resource Processing (CSRP) has supported a research program to foster regional synergies developments. Current projects concentrate on two Australian regions, Kwinana in Western Australia, and Gladstone in Queensland. Building upon the many diverse synergies that already exist in these regions, the research provides practical assistance to industry with the identification and development of new synergies that have sound business cases plus strong sustainability benefits. To complement these applied activities, a customised practically-orientated toolkit is being developed for the systematic identification and evaluation of synergy opportunities and assessment of appropriate technologies. This paper highlights the leading research outcomes and experiences from the CSRP Regional Synergies Program and outlines how the toolkit and expertise can be applied in other industrially intense regions.

Keywords: Minerals processing; Environmental; Recycling; Modelling

1. Introduction

Australia is distinctive among industrialised economies for its degree of dependence on the mining and minerals sector. The direct contribution of the minerals sector to Australia’s GDP was around 4% in 2004 (Mélanie et al., 2006). 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) and extractive metallurgy (extraction of the mineral or metal from the ore, most often through combinations of high temperature processing (pyro-metallurgy, in smelters) and chemical leaching (hydrometallurgy)). Processing takes place in Australia at or near to the mine site (for instance gold, base metals) and/or in heavy industrial complexes (for instance bauxite and mineral sands). Over the last two to three decades, mining and minerals processing companies 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 transformations and phase changes 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 realisation of regional resource synergies. These concern the capture, recovery and reuse of previously discarded by-products (materials, energy and water) 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.

Industrial regional synergies allow minerals processing operations to not only reduce their overall footprint but also provide an ideal mechanism for making significant steps down the sustainable development path. In essence, industrial regional synergies result in reduced use of virgin feed material and far greater re-use of waste or by-product material, and thus saleable product (e.g., metal concentrate) is produced with better resource utilisation and less wastage generation. Although this makes good sense in sustainability terms, minerals processing industrial regions have traditionally not operated in this manner. With the increasing desire of the mining industry to embrace sustainability into their business practices, there was a need to develop and provide a practically-orientated approach to the identification and realisation of industrial synergies in intense minerals processing regions.

Recognising the important contribution regional synergies can make towards sustainable minerals processing, the Centre for Sustainable Resource Processing (CSRP) funded research into the development of practical tools for enabling of regional synergies, and supported research projects to further develop and implement industrial synergies in Australian intense industrial regions (e.g., Kwinana and Gladstone) (van Beers et al., 2007). This paper highlights the leading practical research outcomes and experiences from the CSRP Regional Synergies Program and outlines how the toolkit and expertise can be applied in other industrially intense regions. Curtin University of Technology and the University of Queensland are the two current research providers for the CSRP Regional Synergies Program.

Throughout this paper, 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 realises a benefit from co-location with its main customers, a phenomenon well-known as agglomeration economics (Desrochers, 2004). These supply chain synergies therefore do not meet the criterion of 'resource exchange between traditionally separate industries' as the distinctive feature of industrial symbiosis (Chertow, 2000). However once matured, utility and by-product synergies de facto become new supply synergies (van Berkel, 2006).

2. Kwinana and Gladstone industrial areas

2.1. Key characteristics

The Kwinana Industrial Area is a coastal strip of 8 km located approximately 40 km south of Perth (Western Australia). The area was established in the 1950s to accommodate the development of major resource processing and other heavy industries in Western Australia. About 3600 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 annually (SKM, 2002). There is a coexistence of diverse and non-competitive processing industries in the Kwinana area, such as alumina, nickel, and oil refineries, chemical factories, power plants, a cement manufacturer, and fertiliser plants.

Gladstone is situated some 550 km north of Queensland’s capital, Brisbane. It is one of the most industrially-intense areas in Australia, and generates 27% of Queensland’s and 7.6% of Australia’s total volume of exports valued at over A$5 billion annually (GEIDB, 2006). Today several major industries operate in the region, including two alumina refineries, an aluminium smelter, a coal-fired power station, cement plant, chemical plant, and a proposed shale oil mine and processing plant. There are also several smaller companies that support the major industries.

Although both Kwinana and Gladstone are heavy industrial areas, the mix of industries, geography, and organisational set-up is different as illustrated in Table 1. Kwinana has a diverse blend of key processing and manufacturing industries primarily producing for international markets with limited local competition. Its ownership is diversified, 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 aluminium related operations supported by utility industries (e.g., energy, water, port facilities). Rio Tinto Aluminium wholly owns and operates one of the alumina refineries, has part ownership of the other alumina refinery, has majority ownership of the aluminium smelter and has part ownership of the power station. Kwinana accommodates 15 major process industries in an 8 by 2 km coastal strip, whereas industries in Gladstone are fewer (6 major processing industries) and located further apart (in a regional centre with radius of approximately 20 km).

Both Kwinana and Gladstone have industry organisations: the Kwinana Industries Council (KIC) and the
Gladstone Area Industry Network (GAIN). KIC is an incorporated business association and advances a broad range of common interests of the companies in the Kwinana Industrial Area. It pursues its goals through a number of committees set up to provide input on issues of common interest to the member companies. GAIN is different to KIC. It has a number of committees made of representatives from the member companies who provide their time and commitment as part of the usual job responsibilities. These two industry bodies provide an avenue for discussion of issues of common interest amongst their respective local industries and a mechanism for progressing collaborative activities.

2.2. Existing synergies

Prior to the commencement of the CSRP regional synergies research projects, close collaboration and integration already existed to varying degrees in both the Kwinana and Gladstone regions, as illustrated by details presented in Table 2. The existing synergies in both regions were developed in response to perceived business opportunities and environmental and resource efficiency considerations. There are currently 47 and 5 existing regional synergies in Kwinana and Gladstone, respectively. Kwinana compares extremely favourably with the renown international examples of regional synergy development (e.g., Kalundborg in Denmark, Rotterdam in The Netherlands), in terms of the level and maturity of the industry involvement and collaboration. In fact, in a recent study (Bossilkov et al., 2005) Kwinana had the greatest number of regional synergies of all industrial areas surveyed throughout the world. Although Gladstone has significantly fewer synergies, these are major initiatives in their own right, and compare well with other industrial regions. Specifically Kwinana stands out with regard to the number, diversity, complexity and maturity of existing synergies. Gladstone is an example with unusually large geographic boundaries and a high dominance of one industry sector (alumina and aluminium and its power supplier).

Some illustrative examples of existing by-product and utility synergies in Kwinana and Gladstone are listed below. A comprehensive overview of the existing by-product and utility synergies in both regions is provided in van Beers (2006) and Corder (2005).

2.2.1. Gypsum reuse (by-product synergy)

CSBP chemical plant in Kwinana produced gypsum, calcium sulphate, as a by-product of the manufacture of phosphoric acid. This material was stockpiled at one of the CSBP’s sites during the 1980s. Even though this practice has ended long ago, there remains a stockpile of some 1.3 million tonnes of gypsum. CSBP has extensively reviewed reuse options for this material including the use in plasterboard, sale to farmers, and use in soil amendment. During this research process, it was determined that the material could be utilised by Alcoa’s Kwinana 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.

2.2.2. Hydrochloric acid reuse (by-product synergy)

Dilute hydrochloric acid is generated from scrubbing the gas stream from the chlorination step in the titanium dioxide pigment plant at Tiwest. The acid was previously neutralised in the waste treatment plant. Two initiatives were realised during 1997 to recover the hydrochloric acid: (1) as acid for sale and (2) for production of ammonium chloride to be used at the synthetic rutile production operation. By-product hydrochloric acid is now transferred to neighbouring Coogee Chemicals, which converts it to ammonium chloride and tankers it for use to Tiwest’s synthetic
rutile plant some 75 km from the Kwinana refinery. The cost of the ammonium chloride to Tiwest is significantly cheaper than that previously imported (DEH, 2001).

2.2.3. Fly ash reuse (by-product synergy)

Pozzolanic Enterprises, a subsidiary of Cement Australia, collects fly ash from the Gladstone power station for use as 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. 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.

2.2.4. Cogeneration plant (utility synergy)

The Kwinana Cogeneration Plant (116 MW capacity) is located on land leased from the BP Kwinana oil refinery. The facility produces all process steam for the refinery, and generates electricity that used is by BP as well as supplied to the grid. The cogeneration plant, which is fired with natural gas supplemented with excess refinery gas, was built in 1996 to replace the old BP steam boilers. This synergy has resulted in an estimated reduction of carbon dioxide emissions of about 170,000 tonnes per annum, and allowed BP to decommission its old inefficient boilers, resulting in an estimated savings in capital expenditure of AS15 million. It also ensured a cost competitive reliable source of steam and electricity for the refinery. Moreover the refinery has achieved greater process efficiencies as a result of the greater and more flexible availability of high-pressure steam from the cogeneration facility. The cogeneration plant discharges its wastewater to BP’s wastewater treatment facility.

2.2.5. Water reuse (utility synergy)

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 an additional 15% water restrictions some six months later. Queensland Alumina Limited 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 Limited 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 Limited 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).

2.2.6. Emerging synergies around HIsmelt pig iron plant

In Kwinana, a major new industrial development that further enhances regional synergies in the region is the world’s first commercial 800,000 tonnes/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\textsubscript{2}), 40% reduction of nitrogen oxides (NO\textsubscript{x}), and 90% reduction of sulphur oxides (SO\textsubscript{x}) compared to blast furnace steel production. Upon completion of commissioning (which began in November 2004) 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 utilise 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).

The dynamic nature of industry developments 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.

3. Benefits and success factors of regional synergies

3.1. Sustainability benefits

Successful synergies must benefit all involved parties. This is a critical factor, as no single party would participate in a potential synergy initiative if they thought it was to their disadvantage. For all synergy examples presented in this paper there are both tangible operating benefits as well as less tangible, such as reputation, environment or community benefits. Experience from both the CSRP Kwinana and Gladstone regional synergy projects has demonstrated this conclusion quite clearly. This is illustrated in Table 3, which presents a summary of the commercial, environmental, and community benefits for the synergy examples presented in previous section.

As illustrated in Table 3, the types of benefits can vary greatly and often go well beyond the conventional business case benefits. Security of water and energy supply, increased energy efficiency, lower operational costs for energy use, and reduced storage costs for the inorganic by-products are key benefits from regional synergies presented here. In addition, all of these synergies had environmental and community benefits. These case-studies exemplify that the benefits from regional synergies are not just commercial but also strategic, leading to reduced exposure to risk and better reputation with key stakeholders. The critical factor in initiating a regional synergy is for...
all the involved parties to appreciate fully the range of benefits, both direct and indirect, that will result from its implementation (Corder et al., 2006). This is often difficult to do as the benefits cannot be easily evaluated using conventional business case models, such as discounted cash flow.

3.2. Success factors

The realisation of successful synergies is dependent on three main aspects: proven technology, convincing business case, and licence to operate (van Berkel, 2006). Proven and viable process technologies and equipment are necessary to develop a regional synergy. The by-product must be transported between sites and may need to be processed to meet technical and market requirements. Without a suitable technology available to convert or transport the by-product, a synergy project is not feasible. Once a potential technical synergy ‘match’ has been identified (that is a realistic technical opportunity for a by-product that is being generated at one operation being used at a neighbouring operation) both the by-product generating and receiving operations need to identify the business case in developing this synergy. In addition, there must be compelling evidence that financial, environmental, and community benefits outweigh the project costs and risks.

The less tangible or ‘softer’ benefits can be a strong driver for change and are usually much more difficult to control than associated technologies. If, for instance, the local community perceives an industry is having an undesirable impact on lifestyle through wastes, emissions or disposal practices, this could affect the company’s ‘licence to operate’, even if the company is satisfying the government regulations. Community outrage has the real potential of making it very difficult for a company to operate in a particular region if measures are not implemented to address community concerns. The development of regional synergies is one practical measure to satisfy these concerns.

4. Enhancing regional synergies in Australia: practical support to industries

As outlined in previous section, there are already significant number of successful regional synergies in Kwinana and Gladstone. More potential synergy opportunities appear to exist in both areas which, upon implementation could benefit industry, the environment and the community. To further enhance the development of such potential regional synergies, the Centre for Sustainable Resource Processing (CSRP) commissioned research projects in 2004 to facilitate the identification of potential synergies and assist industries with their implementation in Kwinana and Gladstone, and efforts are well underway to start similar projects in Geelong (Victoria, Australia) and Rustenburg (South Africa).

4.1. Kwinana

In Kwinana, over 90 synergy opportunities have been identified by the CSRP Kwinana Synergies Project 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. 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 Kwinana Industries Council (KIC). Based on the interest and perceived importance by the KIC and the industries, current development efforts focus on ten short-listed
priorities, with regard to water (e.g., reuse of treated industrial effluents, demineralised water, and treatment of oily wastewater) and by-products (e.g., recovery and reuse of sodium sulphate, ammonium sulphate, catalysts, and grain waste). In addition to the feasibility work on the one-on-one company synergies, the research also contributes to the development of collective strategies for the Kwinana Industrial Area on the recovery and reuse of inorganic by-products, water, and energy. These efforts have a more long-term and strategic focus, and include most major Kwinana industries (van Beers, 2006).

4.2. Gladstone

In Gladstone, a database was established of material, energy and water inputs and by-product generation from the principal companies (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. Although 30 possible opportunities were identified, the subsequent focus concentrated on two short-term projects: the consolidation of wastes for use as an alternative fuel source for cement manufacturing, and the (re-)use of ‘fit-for-purpose’ water. These initiatives are being pursued either through the current project or independently by the respective organisations. With regard to long-term projects, opportunities should be assessed for the recovery and re-use of large volume waste streams (bauxite residue and fly ash) and gaseous emissions (carbon dioxide and sulphur dioxide).

4.3. Type and level of research support

The type and level of research assistance to the development of selected synergies depends entirely on the specific research needs of the involved industries. CSRP’s contribution to the development of selected synergies through its respective research project comprises the following elements:

- Facilitation between involved companies.
- Detailed assessment of the by-product stream with regard to volumes and composition.
- Assessment and selection of potential uses and potential combinations thereof.
- Evaluation of pre-processing and source treatment needs.
- Concept design for the synergy project (technology and infrastructure).
- Preliminary assessment of economic, technical, environmental, and social feasibility.
- Assistance in detailed business planning for implementation.

The development of synergies from identification, preliminary evaluation, detailed assessments to implementation is a time-consuming process. It involves multiple parties working together to achieve a common goal. As most opportunities with straightforward and sound conventional business cases (“low hanging fruit”) have been realised in both Kwinana and Gladstone, it is now the challenge for the researchers, industries, and the involved industry organisations (KIC and GAIN) to further develop the more challenging synergy opportunities. The features of these opportunities comprise sound sustainable development credentials with a less than compelling conventional financial case (e.g., project net present value is somewhat below standard requirement). These synergies will only come to fruition if through dedicated research and practical support it is possible to demonstrate to the industries the overall benefits of these projects. Implementing such projects will enhance the sustainability of both the Kwinana and Gladstone regions.

5. Existing approaches for progressing regional synergies

Early on in this project, a detailed review of best practices of regional synergy development from around the world was undertaken (Bosilkov and van Berkel, 2005) with the purpose of determining the key factors that encourage and facilitate the greater utilisation of regional synergy opportunities in minerals processing intense regions. The study results revealed that regional resources synergies have so far developed opportunistically in the absence of specific methods for synergy option generation, and that there was a need for structural development of synergy opportunities with particular relevance to minerals processing regions. In addition, the study also exposed the lack of attention given to technological and engineering challenges specifically associated with regional synergy development. Without a rigorous and systematic approach to regional synergy identification and implementation, it is likely that potential opportunities would be missed.

Based on these principal outcomes, possibly the first of its kind in relation to industrial synergies, there was a strong and well-defined need to produce a practically-oriented toolkit that could be easily applied by engineers or technologists in intense minerals processing regions. To complement the practical facilitation projects in the case-study areas (e.g., Kwinana and Gladstone), the CSRP initiated a foundational research project with the specific aim of developing an engineering and technology platform for regional resource synergies. Details on this CSRP toolkit are presented in the next section (New tools for enhancing regional synergies).

Traditional engineering tools focus on modelling and optimisation of material and energy flows within a process or a facility. The flow of material and energy between multiple facilities poses a new challenge to these tools, in terms of the number of material and energy flows and unit...
operations to be evaluated and consideration of distance (typically ignored at the facility level). Despite the existence of some synergy identification tools, it was found that their use had been very limited with no clearly defined benefits (Bossilkov et al., 2005):

- The predominant type of tool used generally to try to “match-up” generators of waste with companies or individuals interested in recycling or reusing these materials is the “waste-exchange” tool. This type of service is widely spread in UK, USA and Canada, and its effectiveness is largely dependent on the supply and demand posted.
- The most widely cited tool for Industrial Ecology design is the Industrial Materials Exchange (IME) tool. It is intended for use in the identification and analysis of by-product synergies, as well as for planning new eco-industrial projects. The IME tool is a proprietary tool developed by Bechtel Corporation (now Nexus), not available to users outside Bechtel. It has been used in Brownsville, Texas region (BCSD-GM, 1997) and in the demonstration project in Tampico, Gulf of Mexico (Young, 1999).
- A similar tool was developed by USEPA in 1997 to help users to identify, screen and optimise by-product utilisation opportunities at a regional scale. Facility Synergy Tool (FaST), is a database application that helps a user to identify potential matches between non-product outputs and the resource requirements (material and energy) of common industrial processes. The tool has been applied in the design and planning of the Eco-Industrial Park (EIP) in Burlington, Vermont (Industrial Economics, 1998). The database has a major limitation, since it contains a limited number (35) of pre-determined input/output facility profiles.
- The Industrial Ecology Planning tool (Nobel, 1998) tool incorporates a Geographic Information System (GIS) to help identify feasible water reuse networks and to allow transportation costs to be explicitly included in the optimisation of these networks. This tool was used to identify and optimise water use and reuse opportunities within a complex of approximately 20 different industrial facilities at the Baytown Industrial Complex in Pasadena, Texas.
- Water PINCH has been applied in an industrial ecosystem project in the Rotterdam, The Netherlands, where it showed the possibility to develop an optimal water use and cascade circulation both within companies as well as in clusters of companies (Baas, 1998).

In the best practice review (Bossilkov et al., 2005) it was observed that recent or current activity in terms of ongoing efforts for identification and further implementation of synergy opportunities is evident in six of the 18 industrial regions reviewed (including Kwinana and Gladstone). For the remainder, despite likely good intentions, there has been no follow-up. The process for comprehensive identification of all potential synergies in a given industrial region needs proper facilitation and resourcing, requiring input from all parties at every stage. Such input includes awareness and recruitment, data collection, analysis/synergy identification, pre- and feasibility analyses, and/or implementation. The process can be very taxing on the participating companies’ human resources, often competing with usual business activities.

The employment of tools aiding the identification of synergy opportunities is featured in only two of the industrial regions reviewed. It is also evident that the prevalence of the identified synergies in all regions involves straightforward exchanges, with minimal if any processing of the waste stream. This implies that current regional synergies efforts only identify a small number of potential opportunities and, thus, a simpler, straightforward approach is needed to promote and advance the process for development of regional synergies. There is sufficient evidence that a committed approach to industrial synergies ultimately brings both economic and environmental benefits to the industries and communities involved.

Using the data and information collected from the best practices review as a basis, a web-based compendium of real synergies has been compiled showcasing the benefits that synergies can bring to industrial regions. This compendium, known as the CSRP Global Synergy Database, is an output from CSRP research activities and is readily available at www.csrp.com.au/database. Its purpose is to provide a publicly available database of synergy examples from around the world, which can be easily searched and accessed to aid in the development of synergies worldwide.

6. New tools for enhancing regional synergies

As mentioned in the previous section, the outcomes from the best practices review study (Bossilkov et al., 2005) highlighted the need for a strong and well-defined practically-orientated toolkit which could be easily applied by engineers or technologists in intense minerals processing regions. As a result, a key focus of CSRP research has been on the development of a toolkit to meet these needs. The toolkit comprises two key components:

- Regional Eco-Efficiency Opportunity Assessment Methodology: tools for the identification and the development of potential synergy opportunities.
- Technology Assessment Methodology: assessment of technology needs and opportunities for regional synergies involving water, energy and materials recovery and processing.

6.1. Regional eco-efficiency opportunity assessment methodology

In order to systematically identify and facilitate the identification and development of synergy opportunities
in a less demanding way, a Regional Eco-Efficiency Opportunity Assessment Methodology is currently being developed through CSRP (Bossilkov et al., 2005). In its final version it will comprise a number of enabling tools, such as datasheets, various templates and most importantly a set of application tools that facilitate and aid organisations in deciding the synergy opportunities with the best potential. The methodology is currently targeted for use by facilitator/s for initiation or enhancement of regional synergy developments. However it may also be useful for companies looking for an outlet for one or more of their outputs or looking for an alternative input/s.

The experience from CSRP applied research activities in Kwinana and Gladstone has demonstrated the difficulty of accessing quantitative and qualitative data characterising industrial inputs and outputs for various reasons, e.g., confidentiality concerns, absence of quality data, lack of time or motivation, etc. Despite the existence of a facilitating structure in both regions (Kwinana Industries Council and Gladstone Area Industry Network) engaging industry partners for the purposes of participating in various meetings and workshops is often challenging due to the pressures of their daily job requirements. Further more, discussion with companies in the Kwinana Industrial Area has concluded that companies are interested in what the potential synergies are and what are their likely benefits in terms of economic, environmental and community benefits as well as some preliminary indication on technical, economical and regulatory feasibility. To address these challenges, it was necessary to design the toolkit with the following characteristics:

- Simplicity – does not require training as a prerequisite and contains an intuitive flowchart for guidance.
- Suit data availability – is designed to accommodate data that could be provided from an industrial operation with minimal effort.
- Reduction of time/resource intensity – is designed to efficiently analyse and identify potential synergy opportunities.
- Provide quick and targeted results – is aimed to provide the user with a comprehensive list of prioritised potential synergy opportunities for further consideration and feasibility evaluation.

The Regional Eco-efficiency Opportunity Assessment Methodology has three stages (Bossilkov et al., 2005):

- preliminary assessment tool,
- inventory tools, and
- screening tool.

Whereas the preliminary assessment tool requires limited data to estimate the potential scope for regional resource synergies in a given industry area, subsequent stages require more detailed information to target synergy opportunities with the greatest potential benefits (see Fig. 1).

6.1.1. Preliminary assessment tool

The Preliminary Assessment Tool aims to provide an overview of potential synergy opportunities within an industrial area and establish the business case for further data collection and identification of prospective synergy projects (Bossilkov et al., 2005). The tool has in-built qualitative information regarding major input and output flows for more than 100 industries with an option of adding new industries or updating the input–output flows, at the discretion of the user. The tool can potentially provide assistance at the later stages of the synergy identification process to specifically target companies that have greater potential to be involved in synergy projects. The output of the Preliminary Assessment Tool is an extensive list of indicative synergy opportunities based on the pre-loaded input/output flow data for each respective industry. The main benefit of this tool is that it narrows down the likely potential synergy opportunities without requiring the collection of detailed data. It is a simple and easy to apply tool that can quickly generate a list a possible regional synergy opportunities. Naturally, the business case and estimated sustainability benefits of these opportunities will depend on a number of factors which are analysed in the next stages of the toolkit.

6.1.2. Inventory tool

The Inventory Tool (Input/Output Inventory Stage) aims to deliver detailed listings of potential synergy opportunities in three main groups: water, energy and by-products. These three groups are designed in a similar manner requiring company-specific information, distances between companies and specific quality and quantity parameters. A number of search functions are provided to allow identification of potential matches as per the user’s specification and generate different output reports (Bossilkov and van Berkel, 2005):

- The Water group assists the user in developing an inventory of effluent and influent water streams of each major water user in the given region. Data on the type of the water stream, quantity, frequency of discharge and an

![Fig. 1. Overview of regional eco-efficiency opportunity assessment methodology (Bossilkov et al., 2005).](image-url)
array of quality parameters (e.g., Total Suspended Solids, Chemical Oxygen Demand, pH, etc.) are required. The water tool thus generates a register of the most likely water synergy opportunities (in terms of volume, quality and distance).

- The **Energy** group assists the user in generating a process energy inventory (waste heat streams and process energy requirements, in particular those most amenable to using lower grade waste heat, e.g., cooling, refrigeration, space heating, process pre-heating, drying, moisture removal, etc.). The energy tool generates a list of the process heat sources and potential sinks in the industrial area, optionally rated on the energy content/requirement, temperature and distance.

- The **By-Products** group assists the user in collating all solid, liquid and gaseous inputs and outputs, excluding water, fuels and power. The materials and by-products are classified into defined categories and subcategories (e.g., category: acids and acid solutions, subcategory: sulphuric acid) which identifies the important components of the stream and thereby increases the chance of successful matching. The tool provides searching and matching sections returning registers of available flows satisfying the search criteria. It can also seek “economies of scale”, whereby similar by-products from several companies are combined into a single stream.

### 6.1.3. Screening tool

The **Screening Tool** assesses the potential contribution to sustainable development for the potential synergy opportunities identified at the previous stage (Bossilkov et al., 2005). The tool is designed to provide direction in the search for the most beneficial synergy opportunities, in terms of their contribution to sustainable development (based on IISD (2002)) as well as their expected feasibility and ease of implementation (technical difficulty, project costs, regulatory approvals and community acceptance). The tool applies a subjective scoring system for a set of related questions within the two themes (see Table 4). In an attempt to reward synergy initiatives that have both strong sustainability credentials and could be implemented relatively easily, the average rating for the set of questions within the two themes are multiplied together to give an overall rating. Based on this overall rating, the screening tool generates a report with priority synergy opportunities for detailed techno-economic evaluation. Such a report can assist industries, facilitator(s), and other involved parties with the strategic guidance on which synergies should or should not be selected for feasibility assessment.

### 6.1.4. Trial of toolkit

The prototype of the developed methodology was tested with data collected as part of the CSRP Kwinana and

<table>
<thead>
<tr>
<th>Category</th>
<th>Sustainability benefits questions</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engagement</td>
<td>Potentially affected communities will be identified and given an opportunity for engagement to ensure that their legal, institutional and cultural characteristics are not compromised</td>
<td>• Definitely not true (1 points)</td>
</tr>
<tr>
<td>People</td>
<td>The project will contribute to people’s well-being and the social/cultural integrity of their community in terms of job creation, worker/population health, safety and well-being</td>
<td>• Unknown, unlikely, or not applicable (3 points)</td>
</tr>
<tr>
<td>Environment</td>
<td>The project will improve resource efficiency (materials, energy, water) and reduce environmental emissions (land, water, air)</td>
<td>True (9 points)</td>
</tr>
<tr>
<td>Economy</td>
<td>The project will have a positive contribution to the long-term viability of the local, regional and national economy and/or will have a positive effect on the company’s financial health in terms of reduction of company’s environmental costs (such as disposal costs, purchase costs, fees, permits, licences, environmental management costs, insurance premiums, waste handling and storage etc.) and enhancement of company’s operational efficiency</td>
<td></td>
</tr>
<tr>
<td>Traditional and non-market activities</td>
<td>The project will respect traditional cultural, recreational, indigenous values in terms of contribution to improve life style, contribution to the long-term viability of the region; maintaining traditional cultural attributes as designated by the local community</td>
<td></td>
</tr>
<tr>
<td>Institutional arrangements and governance</td>
<td>The project builds upon, and where possible enhances existing institutional arrangements, including collaborative networks of industry, government and community.</td>
<td></td>
</tr>
<tr>
<td>Synthesis and continuous learning</td>
<td>The project will strengthen the platform for further regional synergy opportunities in the region</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Category</th>
<th>Ease of implementation questions</th>
<th>Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical difficulty</td>
<td>Technical difficulty of implementation of the project in terms of need for processing treatment, technology requirements, distance (especially for water, gases, and energy), and quantity availability/demand is expected to be</td>
<td>• Low (1 or 9 points)</td>
</tr>
<tr>
<td>Regulatory approval</td>
<td>Expectations that applicable approvals (permits, licences, etc.) to be granted by the relevant regulatory authorities are</td>
<td>• Medium (3 points)</td>
</tr>
<tr>
<td>Community acceptance</td>
<td>Expectations the project to be accepted by the local community and/or other stakeholders are</td>
<td>• High (1 or 9 points)</td>
</tr>
<tr>
<td>Project economy</td>
<td>The project costs are expected to be</td>
<td></td>
</tr>
</tbody>
</table>
Gladstone Synergies Projects (Bossilkov, 2006). The trial concluded that the methodology streamlines and enhances the identification and evaluation of synergy opportunities by providing the user with guidance and support for the tracking of the material, energy and water flows. Generally the methodology produced a suite of potential synergy initiatives that closely matches those identified by the extensive and time-consuming work carried out as part of the Kwinana and Gladstone Synergy. The Preliminary Assessment Tool has also been applied to two industrial regions in Australia, Geelong (Victoria) and Wagga Wagga (New South Wales) (Bossilkov and Corder, 2006) (Corder and Bossilkov, 2006), and all tools will be applied in Rustenburg (South Africa) later in 2007.

6.2. Technology assessment methodology

As outlined earlier in this paper, certain success factors, such as convincing business case, societal license to operate, and proven technology, are necessary to realise regional synergy opportunities. These success factors put technology in the spotlight as a potential enabler for regional resource synergies, which had so far not been readily apparent (Bossilkov et al., 2005). In order to assess the role of technology in the realisation of regional resource synergies, a Technology Assessment Methodology was developed. This is an analytical framework that breaks down a potential synergy opportunity in three components: capture, recovery/management and utilisation (as in Fig. 2) (Harris et al., 2006). Capture refers to how the material/heat/water is taken from the ‘source’ production process. This recognises that the composition, or quality of a by-product stream, is dependent on the technology and processes used in production. Recovery then refers to the technology used when the resource stream (water/heat/material) is recovered, separated into valuable components, transformed or mixed with another resource to form a usable by-product. The transport and storage (enabling infrastructure) of by-products is also important and is considered under the recovery/management component. Utilisation then refers to the technology involved when the by-product stream is used in a production process. To illustrate the framework, consider past production of titanium dioxide pigment at Tiwest in Kwinana. The manufacture of titanium dioxide pigment generated a dilute hydrochloric acid from the scrubbing of the tail gas from the chlorinators, which was then neutralised in the company’s wastewater treatment plant. Tiwest installed a second scrubber to be able to recover most of the hydrochloric acid as a weak acid that could be taken by the nearby Coogee chemicals works, to produce ammonium chloride which can be used by the Tiwest rutile plant (Clark and Brereton, 2001). The realisation of this synergy thus required capture technology at the source process (second scrubber to collect hydrochloric acid in a useable form), recovery technology for processing (to convert in ammonium chloride) and utilisation technology at the sink process (minor adjustment to feed by-product ammonium chloride).

A preliminary assessment of the technology needs for enhancing regional synergies, using the developed framework covering capture, recovery and utilisation, identified the following technology opportunities (Bossilkov et al., 2005; Harris et al., 2006).

6.2.1. Water

The economic feasibility of any water synergy remains challenged by the currently prevailing relatively low prices for water, in particular in areas where bore water is readily available. This situation is however starting to change with greater consideration for sustained access to water resources in the future. There are many mature water treatment and recovery technologies, and the principal
challenge appears to be to package treatment and recovery technologies in a customised recovery scheme. In broad terms, a choice needs to be made to either produce a ‘design grade’ water quality from a (mixture of) process effluents (as for example the case in the Kwinana Water Reclamation Plant (van Beers, 2006)) or find specific process applications where high grade water can be replaced with lower grade recovered water with no or limited impact on the process ‘fit-for-purpose’ matching, as for example the case with the reuse of secondary treated effluent for mud washing at Queensland Alumina Limited in Gladstone (Corder, 2005)).

6.2.2. Energy/heat

Heat recovery technologies are well established in particular for generating power from higher-grade waste heat from processes, which is typically done within an operation. However, recent examples demonstrate that even recovery of lower grade waste heat can be profitable, either as a lower grade process heat input (for example at Alcoa’s Pinjarra Refinery in Western Australia (van Berkel and Narayanaswamy, 2005)) or even to drive major pieces of equipment (for example the use of medium pressure steam to drive air compressors at HIs melt (van Beers, 2006)). An extension of such schemes over company boundaries is in principle possible, even though the techno-economic viability decreases quickly with increasing distances. This could however in principle be overcome with emerging integrated heat transfer and storage concepts utilising for example phase change materials.

6.2.3. Materials

These synergies cover the re-use of a wide range of solid, liquid and gaseous by-products. While recovery processes are conceivable for many materials, their application typically depends on control, or preferably reduction and elimination, of minor elements from the by-product stream, selective and efficient concentration of materials from gaseous streams and better process controls in hot processes to control hazardous emissions that may occur from use of alternative fuels and raw materials.

6.2.4. Detailed technology assessments

The identified technology needs for regional synergies, as summarised above, feed into detailed technology assessments which will cover the three components of the analytical framework: capture, recovery and utilisation, incorporating both current and emerging technologies. The detailed technology assessments will highlight and evaluate the required technologies to enable synergies that current technologies do not cater for, and will aid industries to select appropriate technologies to enable regional synergies. The Technology Assessment Methodology, which is currently under development, will, when complete, generate a list of commercially-available technologies for the capture, recovery and utilisation of by-products for identified synergy opportunities. In addition, it will provide indicative cost estimates for the required technologies so that an approximate estimate of the financial viability, namely determining if the net present value (NPV) is greater than zero, can be made.

The Technology Assessment Methodology will complement the Regional Eco-Efficiency Opportunity Assessment Methodology so that the complete toolkit will identify and rank potential synergy opportunities, determine the most appropriate technologies and provide an indicative estimate of the viability of the potential synergy opportunity.

7. Conclusions

Regional resource synergy developments in Kwinana and Gladstone compare favourably with well-regarded international examples (e.g., Kalundborg (Denmark), Rotterdam (The Netherlands), Forth Valley (Scotland)) (Bossilkov et al., 2005), in terms of the level and maturity of the industry involvement and collaboration. Specifically, Kwinana stands out with regard to the number, diversity, complexity and maturity of existing synergies. Gladstone is as an example with unusually large geographic boundaries and unusually high dominance of one industry sector (alumina and aluminium and its power supplier).

Overall there is enthusiasm from industry to achieve greater regional synergies although the commitment varies from one industrial region to another, depending on the key local drivers and barriers. The need for industry to work together on regional synergy opportunities is critical for their success. Many diverse regional synergy opportunities still appear to exist in both Kwinana and Gladstone, mostly in three broad areas: water efficiency and exchanges; energy efficiency and exchanges, and industrial inorganic by-products reuse. Over the past few years significant progress has been made by the industries, research teams, and the local industry organisations to further develop regional synergies. It is clear that the development of synergies from identification, preliminary evaluation, detailed assessments to implementation takes time. It involves multiple parties working together to achieve a common goal which is often not perceived as core business.

The synergy engineering and technology research, conducted in parallel with the practical synergy facilitation projects, is delivering a toolkit to provide a rigorous and systematic approach for identifying and evaluating synergy opportunities and associated technologies within an industrial area. The trial application of the Regional Eco-Efficiency Opportunity Assessment Methodology in Kwinana and Gladstone demonstrated its value in contributing to the collaborative development of synergies. The final toolkit, will not become a stand-alone solution but should be used effectively as a supplementary instrument, in conjunction with an applied pragmatic approach, to streamline the identification and evaluation of synergy opportunities and associated technologies.
Acknowledgement

The research reported here is supported by the Centre for Sustainable Resource Processing (www.csrp.com.au), which has been established under the Australian Common-wealth Cooperative Research Centres Program.

References