Centre of Excellence in Cleaner Production
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Application of the Cleaner Production Framework to the Development of Regional Synergies in Heavy Industrial Areas: A Case Study of Kwinana (Western Australia)

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STATEMENT

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgement has been made. This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

Dick van Beers

Date: ______________________

Place: ______________________

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ABSTRACT

The aim of the PhD research is to examine the effectiveness of drawing common elements of regional synergy development into an overall framework, generally used for the implementation of cleaner production, to assist industries in heavy industrial areas with the further development of regional synergy opportunities. The literature review revealed an absence of practical methodologies to support industry with the development of promising synergy opportunities. An assessment of existing synergies in the case-study region (the Kwinana Industrial Area) has confirmed the close collaboration and integration which already exists in the region. These existing synergies provide a range of sustainability benefits. The research resulted in customised methodologies to assist in the advancement of regional synergies, focussed on the priority themes of: inorganic by-products, water, and energy. The trial application of the methodologies demonstrated their effectiveness in delivering valuable outcomes for the stakeholders involved (e.g. feasible synergy opportunities for industry uptake). Overall, the cleaner production framework is not a driver for synergy development perse, but rather should be regarded as a flexible framework to advance synergy development – targeted towards specific local research needs. Strengths of the novel methodologies include added-value to stakeholders, stakeholder participation, transparency and flexibility. The principal weakness concerned the time investment to apply the methodologies. However, it is anticipated that the trialled methodologies could be performed in other regions in a significantly shorter time period (by learning from the experiences here). A set of parameters must be understood before applying the customised methodologies in industrial regions elsewhere in the world. These include: distances between industries, number and diversity of industries, industry interest, industry champions, presence and functioning of an industry organisation, relevant regulations, community support, availability of know-how and expertise, funding, and corporate culture.

AUTHOR'S JOURNAL PUBLICATIONS ARISING FROM THIS WORK

Journal Publication	Relevant Chapter
Van Beers, D., G. Corder, A. Bossilkov, and R. Van Berkel. 2007. Regional Synergies in the Australian Minerals Industry: Case-Studies and Enabling Tools. Minerals Engineering 20(9): 830-841.[1]	Chapters 2, 3, 4, and 5
Van Beers, D., G. Corder, A. Bossilkov, and R. Van Berkel. 2007. Industrial Symbiosis in the Australian Minerals Industry: The Cases of Kwinana and Gladstone. Journal of Industrial Ecology 11(1): 55-72.	Chapter 4
Van Beers, D., A. Bossilkov, and C. Lund. 2009. Progressing the Reuse of Inorganic By-Products: The Case of Kwinana, Western Australia. Resources, Conservation and Recycling 53 (7): 365-378.	Chapter 6
Van Beers, D., A. Bossilkov, and R. Van Berkel. 2008. A Regional Approach Using Synergy to Advance Sustainable Water Use: A Case Study Using Kwinana (Western Australia). Australasian Journal of Environmental Management 15 (September): 149-158.	Chapter 7
Van Beers, D. and W. Biswas. 2008. A Regional Synergy Approach to Energy Recovery: The Case of the Kwinana Industrial Area, Western Australia. Energy Conversion and Management 49: 3051-3062.	Chapter 8

[1] Journal paper arising from conference paper presented at Material, Minerals, and Metal Ecology Conference (MMME), 2006, South Africa.

AUTHOR'S CONFERENCE PUBLICATIONS RELEVANT TO THESIS

Conference Publication (Listed in Chronological Order)	Relevant Chapter
Van Beers, D., C. Oughton, and D. Cooling. 2007. Update on Regional Synergy Development in the Kwinana Industrial Area. International Conference on Engineering Sustainability, 31 October – 2 November, Perth, WA, Australia.	Chapters 2, 4, 6, 7, and 8
Van Beers, D. and R. Van Berkel. 2007. Collaborative Industry Research to Develop Regional Synergies: Experiences and Lessons from Kwinana (Western Australia). 4th International Conference of the International Society for Industrial Ecology, 17-20 June, Toronto, Canada.	Chapters 4, 6, 7, and 8
Van Beers, D., Corder, G.D., Bossilkov, A., Van Berkel, R. 2006. Enhancing Water Efficiency Through Regional Cooperation – The Case of Kwinana. Water in Mining Conference, 14-16 November, Brisbane, QLD, Australia.	Chapter 7
Van Beers, D., G. Corder, A. Bossilkov, and R. Van Berkel. 2006. Regional Synergies in the Australian Minerals Industry: Case-Studies and Enabling Tools. Material, Minerals, and Metal Ecology Conference (MMME), 14-15 November, Cape Town, South Africa.	Chapters 2, 4, 6, 7, and 8
Swetman, T.E., D. Cooling, and D. Van Beers. 2006. Regional Synergies in the Kwinana Industrial Area: Lessons Learnt and the Way Forward. Waste and Recycling Conference, 19-22 September, Fremantle, WA, Australia.	Chapters 4, 6, 7, and 8

List of Thesis Conference Publications

Conference Publication (Listed in Chronological Order)	Relevant Chapter
Corder, G.D., D. Van Beers, J. Lay, and R. Van Berkel. 2006. Benefits and Success Factors of Regional Resource Synergies in Gladstone and Kwinana. Green Processing Conference, 5-6 June, Newcastle, NSW, Australia.	Chapters 4, 6, 7, and 8
Van Beers, D. and R. Van Berkel. 2006. Regional Synergy Implementation and Research in Australia: the Case of Kwinana. 2nd Asia-Pacific Eco-Business Forum in Kawasaki - Urban and Industrial Symbiosis, 23-25 January, Kawasaki, Japan.	Chapters 2, 4, 6, 7, and 8
Van Berkel, R., D. Van Beers, and A. Bossilkov. 2005. Regional Resource Synergies for Sustainable Development: The Case of Kwinana. Materials and Testing 2005 Conference, 30 October - 2 November, Fremantle, WA, Australia.	Chapter 6
Van Beers, D., R. Van Berkel, and A. Bossilkov. 2005. Update on Industrial Symbiosis in the Kwinana Industrial Area. 2nd Conference of the International Society for Industrial Ecology, 12-15 June, Stockholm, Sweden.	Chapters 4, 6, 7, and 8
Bossilkov, A., D. Van Beers, and R. Van Berkel. 2005. Industrial Symbiosis as an Integrative Business Practice in the Kwinana Industrial Area: Lessons Learnt and Way Forward. 11th International Sustainable Development Research Conference, 6-8 June, Helsinki, Finland.	Chapters 4, 6, 7, and 8

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LIST OF ABBREVIATIONS

Abbreviation	Description
A$	Australian dollar (A$ 1 = ~ US$ 0.9)
ANZECC	Australian and New Zealand Environment Conservation Council
ARC	Australian Research Council
BOD	Biological oxygen demand
CCC	Conventional combined cycle
CCD	Coal combustion products
CECP	Centre of Excellence in Cleaner Production
COD	Chemical oxygen demand
CSRP	Centre for Sustainable Resource Processing
EE	Eco-efficiency
GIS	Geographic Information System
GJ	Giga Joule (1 GJ = 1,000 MJ)
HEX	Heat exchanger
IE	Industrial ecology
KC	Kalina cycle
KIA	Kwinana Industrial Area
KIC	Kwinana Industries Council
kWh	Kilowatt hour
KWRP	Kwinana Water Reclamation Plant
MJ	Mega Joule (1 MJ = 1,000 KJ)
MWh	Megawatt hour
NPV	Net Present Value
ORC	Organic Rankine cycle
PP	Pollution Prevention
RRS	Regional resource synergy
SDOOL	Sepia Depression Ocean Outlet Landline
TDS	Total dissolved solids
TJ	Tera Joule (1 TJ = 1,000 GJ)
TSS	Total suspended solids
UNEP	United Nations Environment Program
USEPA	United States Environmental Protection Agency
WA	Westerns Australia
WBCSD	World Business Council for Sustainable Development
WHB	Waste heat boiler
WWTP	Wastewater treatment plant

GLOSSARY

Word	Explanation
By-product synergy	The use of a previously disposed by-product (as solid, liquid, or gas) from one facility by another facility to produce a valuable product (e.g. recovery and on-selling of carbon dioxide and hydrogen).
Cleaner production	The continuous application of an integrated preventive strategy to processes, products, and services to increase the eco-efficiency and reduce risks to humans and the environment (UNEP 1994b; ANZECC 1998).
Industrial ecology	A concept in which an industrial system is viewed not in isolation from its surrounding system but in concert with them (Jelinski et al. 1992). Industrial ecology employs a holistic view to study, assess and improve the utilisation of natural resources (materials and energy) in an industrial society (Van Berkel et al. 1995).
Kwinana Industrial Area	A coastal strip of 8 km located approximately 40 kilometres 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. There is a coexistence of diverse and non-competing processing industries in the Kwinana Industrial Area, such as alumina, nickel, and oil refineries, chemical factories, power plants, a cement manufacturer, and fertiliser plants.
Kwinana Industries Council	An incorporated business association with membership drawn from all the major industries and many of the smaller businesses in the Kwinana Industrial Area. The KIC was formed in 1991, striving to foster positive interaction between member companies and with its major stakeholders. Website: www.kic.org.au.
Regional resource synergy	A process that "engages traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and/or by-products. The keys to industrial symbiosis (regional synergies) are collaboration and the synergistic possibilities offered by geographic proximity" (Chertow 2000).
Supply chain synergy	Featuring local manufacturer and dedicated supplier of principal reagents for core process industries (e.g. production of ammonia and chlorine for industrial use).
Utility synergy	The shared use of utility infrastructure, and mainly evolves around water and energy (e.g. water recovery and cogeneration).

1 INTRODUCTION

1.1 Background

Regional resource synergies concern the capture, recovery and reuse of previously discarded by-products (also termed “wastes”) from one industrial operation, by other, traditionally separate, industries operating in close proximity (Chertow 2000). The realisation of regional synergies in industrial areas with intensive minerals processing provides a significant avenue towards more sustainable resource processing by reducing emissions and wastes and more efficient use of resources (e.g. raw materials, water, energy). To date, the world-wide evolution of regional synergies has generally been ‘self organising’ as industries pursue business opportunities from collaboration and resource sharing, rather than the result of a structured and planned development. There is an absence of specific methods for synergy option generation and/or synergy technology selection and assessment. This is despite an existing competency and track record in cleaner production methods and metrics and resource recovery technologies, on which such methods could be based (Bossilkov et al. 2005).

The current research investigates the effectiveness of drawing common elements of regional synergy development into an overall framework - generally used for the implementation of cleaner production - to assist industries in heavy industrial areas with advancing regional synergy opportunities.

The often-quoted iconic example of regional synergy development at Kalundborg (Denmark), illustrates the benefits of regional synergies (Ehrenfeld and Gertler 1997). From an Australian perspective, Kwinana (Western Australia) is a major heavy industrial region with a significant number of successfully operating regional synergies (SKM 2002). Kwinana is home to a diverse industry base centred around resource processing and supported by a group of service industries. The expectation is that more synergy opportunities exist, which, if implemented, could lead to substantial reduction in emissions and increases in resource efficiencies. The Kwinana Industrial Area (KIA) is therefore selected as a case-study for this work.

The targeted outcomes of the PhD research are a set of novel methodologies to assist with the development of regional synergies in industrial areas (e.g. option generation, technology selection, concept development, and feasibility studies), which are both highly practical and of use to both the scientific community and industry.

1.2 Project Aim

The overarching aim of this work is to research the effectiveness of drawing common elements of regional synergy development into an overall framework generally used for the implementation of cleaner production to assist industries in heavy industrial areas with advancing regional synergy opportunities. The work will deliver customised methodologies to assist with the identification and implementation of regional synergies in heavy industrial areas. It is expected that the methodologies will be of significant benefit to industry in assisting to reduce emissions and wastes, and also advance the theory and practice of industrial ecology.

The above aim will be accomplished via:

§ A review of the current status of the theory and practice of regional synergies, including the identification of research gaps in the support to heavy industries with the development of regional synergies;

§ An assessment of existing regional synergies in the case-study area (Kwinana Industrial Area) in order to extract lessons learnt for the development of new synergy opportunities; and

§ The development, application, and evaluation of customised methodologies for priority sustainability themes, based on the cleaner production framework, to advance regional synergies in heavy industrial areas.

1.3 Scope and Limitations

Throughout this thesis, 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 thesis, because such supply synergies are business-as-usual. This means that where a business realises a benefit from co-location with its main customers, it will naturally do so – this effect is 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’, which is the distinctive feature of industrial symbiosis (Chertow 2000). However once matured, utility and by-product synergies de facto become new supply synergies.

The case-study area for this research is the Kwinana Industrial Area. The KIA is an area of about 120 square kilometres located in Western Australia, about 40 kilometres south of Perth. The synergy opportunities being identified and developed as part of the research reported here should be contained with this industrial region, or at least have one Kwinana company involved. Synergies which do not meet these criteria are outside the scope of the research.

The research is centered around providing assistance to companies in industrial regions with the identification, evaluation, and development of promising regional synergy opportunities. The responsibility and outreach of the research can go as far as developing initial business plans for implementation. However, it remains the responsibility of the individual companies to decide whether and how to pursue feasible synergy opportunities.

This PhD research was conducted within the framework of the projects ‘Capturing Regional Synergies in the Kwinana Industrial Area’ (Short title: ‘Kwinana Synergies Project’) and ‘Kwinana Industrial Inorganic By-Products Reuse’, commissioned by the Centre for Sustainable Resource Processing (CSRP). The research was conducted at Curtin University of Technology (a core participant of CSRP) through its Centre of Excellence in Cleaner Production (CECP) in close collaboration with the Kwinana Industries Council (an associate participant of CSRP).

In parallel with the research presented here, the CSRP has been developing an electronic Regional Synergy Toolkit (Bossilkov and van Berkel 2005). The toolkit focuses on a targeted identification, prioritisation and evaluation of potential synergy opportunities. The project also focused on an assessment of technology needs and opportunities for regional synergies involving water, energy and materials recovery and processing. The toolkit development utilises the outcomes of the applied research presented in this thesis. Research into the development of the CSRP Regional Synergy Toolkit and results from its trial application in the KIA are outside of the scope of this thesis, and are discussed elsewhere (Bossilkov 2006; Van Beers et al. 2007c). The main differences and overlap between the scope of work of this PhD and the CSRP Regional Synergy Toolkit are presented in Table 1.1.

Table 1.1: Differences and Overlaps between This PhD and CSRP Regional Synergy Toolkit

	This PhD	**CSRP Regional Synergy Toolkit**
Differences	Development of methodologies and approaches, the focus of PhD is not on development of electronic toolkit and its trial application	Development and trial application of electronic toolkit
	Methodologies developed independently from CSRP Toolkit. However, methodologies deriving from this PhD benefit from the application of the toolkit	CSRP Toolkit builds upon methodologies, collected data, industry networks developed as part of this PhD
	Based on Cleaner Production framework, covering entire synergy development process from project planning to implementation of synergies	CSRP Toolkit is not based on cleaner production framework, and covers part of the synergy development process (identification, evaluation, and prioritisation of synergy opportunities)
	Sole focus on the Kwinana Industrial Area	Broader focus on heavy industrial areas nationally and internationally (e.g. Kwinana (WA), Geelong (VIC), Wagga Wagga (NSW), Gladstone (QLD), and Rustenburg (South Africa).
Overlap	Both PhD and CSRP Toolkit focus on development on inorganic by-product, water, and energy utility synergies	
	Both PhD and CSRP Toolkit focus on heavy industrial areas and the resource processing sector	
	Both PhD and CSRP Toolkit have been trialled in the Kwinana Industrial Area	

1.4 Thesis Outline

The structure of the thesis is as follows:

- **Chapter 1 'Introduction'** provides the background and overall aim of the research, including the scope and its limitations.

- **Chapter 2 'Literature Review'** provides a comprehensive review of key literature in the field, and the gaps in the literature which led to this work.

- Following up on findings of the literature review, **Chapter 3 'Research Proposal'** defines the gaps identified and provides the details of the proposed research.

- Valuable lessons can be learnt from existing synergies. **Chapter 4 'Existing Regional Synergies'** gives an overview of the current synergies in the KIA, including some detailed illustrative examples and their sustainability benefits. The chapter includes a comparative review of the drivers, barriers, and trigger events for regional synergy developments in Kwinana, and an assessment of common factors of successful synergies.

- An overview of the overall framework for the development and evaluation of new regional synergy opportunities in the KIA is provided in **Chapter 5 'Methodology Framework'**. The approach was compiled by merging common elements of synergy project development into an overall framework generally used for the implementation of cleaner production in companies.

- **Chapter 6 'Methodology to Advance Inorganic By-Product Synergies'** discusses the applied methodology to drive the implementation of inorganic by-product synergies in Kwinana on a significant scale.

§ **Chapter 7 'Methodology to Advance Water Utility Synergies'** presents the customised methodology to identify and evaluate water synergy opportunities, including the results from its trial application in the KIA.

§ The customised methodology developed to identify and evaluate energy recovery opportunities from Kwinana flue gases is presented in **Chapter 8 'Methodology to Advance Energy Utility Synergies'**. The technical, economic, and environmental aspects of a selected cluster of nearby industries are discussed, including the total carbon dioxide mitigation potential in the KIA through the best energy recovery options.

§ The customised novel methodologies for developing inorganic by-product, water, and energy synergies are evaluated in **Chapter 9 'Evaluation of Applied Methodologies'**. This includes a comparative evaluation against the cleaner production framework, a multi-criteria evaluation, and evaluation against the requirements for regional synergy development.

§ **Chapter 10 'Conclusions and Recommendations'** draws research conclusions based on the findings of the previous chapters in order to validate the formulated research question, including recommendations for future research directions.

2 LITERATURE REVIEW

2.1 Introduction

This chapter serves as the literature review for the PhD research. A review of previous work and experiences in the field of cleaner production, industrial ecology, regional synergies, barriers to implementation of resource efficiency projects, sustainable resource processing, the Kwinana Industrial Area, and the water-energy nexus are provided in Sections 2.2 to 2.9 respectively. A critical analysis of the theory, practice, and tools/methodologies relevant to this thesis is included in Section 2.10. At the end of the chapter, the results from the literature review are drawn together to obtain insights into how the literature can help to find answers to the central research question (Section 2.11).

2.2 Cleaner Production

2.2.1 Theory and Concept

Cleaner Production is officially defined as (UNEP 1994b):

> *'The continuous application of an integrated preventive strategy to processes, products, and services to increase the eco-efficiency and reduce risks to humans and the environment'.*

The concept of cleaner production is aimed at progressive reduction in the environmental impacts of processes, products, and services, through preventative approaches rather than control and management of pollutants and wastes after they have been created (UNEP 1994b). Cleaner production is an integrated approach, since it includes all relevant environmental aspects and impacts, and is not confined to one environmental impact category (unlike most end-of-pipe technologies). Moreover, it serves to improve economic and ecological efficiency (eco-efficiency) and contributes to a realisation of environmental risk reduction and management objectives for humans and the environment (ANZECC 1998; EA 2000). Cleaner production is a preventative approach and therefore generally regarded as the fourth stage in the development of environmental strategies (waste dispersion (stage 1), waste control (stage 2), waste recycling (stage 3), and preventative strategies (stage 4) (Van Berkel 2002).

The many case-studies available in the public domain illustrate that cleaner production is a valuable and constructive preventative approach resulting in significant environmental and business benefits for the industries involved through optimisation and modification of their products, processes and services (DEH 2001c; CECP 2004; Baas 1998; EPA 1993; Pagan et al. 2003; Power et al. 2002).

2.2.2 Methodology and Practices

As depicted in Figure 2.1, the cleaner production assessment is usually divided into five phases (de Hoo et al. 2001; UNEP 1994a; Van Berkel 2000b):. Each phase is discussed briefly below:

1. <u>Planning and organisation:</u> this starts once one or more people in the company become interested in cleaner production. These 'promoters' convince key people in the company of the necessity to, or benefits from, adopting cleaner production practices and establish a proper project organisation for smooth execution of the cleaner production assessment.

2. <u>Pre-assessment:</u> the prime objective of this phase is to select one or more audit focus areas. In the subsequent phases, these audit focuses are evaluated in detail in order to identify, evaluate and – as far as these are feasible – implement cleaner production options. The selection of the audit focus areas requires a preliminary identification and evaluation of the cleaner production potential at the plant level. While doing so, a first inventory of obvious options is made as well as an initial estimate of the waste generation costs.

3. <u>Assessment:</u> this phase consists of an in-depth evaluation of the selected audit focus area(s) in order to develop a comprehensive list of available cleaner production options. This requires quantification of the volume and

composition of the various waste streams and emissions as well as a detailed understanding of their causes.

4. Feasibility Studies: these now have to prove whether or not each of the options identified is technically and economically feasible, and whether each indeed creates a net environmental benefit. The level of detail depends on the nature of the options, since options may range from simple operational arrangements, to use of alternative materials or to the replacement of process equipment, and possibly adopting alternative production routes.

5. Implementation and continuation: the feasible prevention measures are implemented and provision taken to assure the ongoing application of cleaner production. The development of such an ongoing program requires monitoring and evaluation of the results achieved by the implementation of the first set of preventive measures.

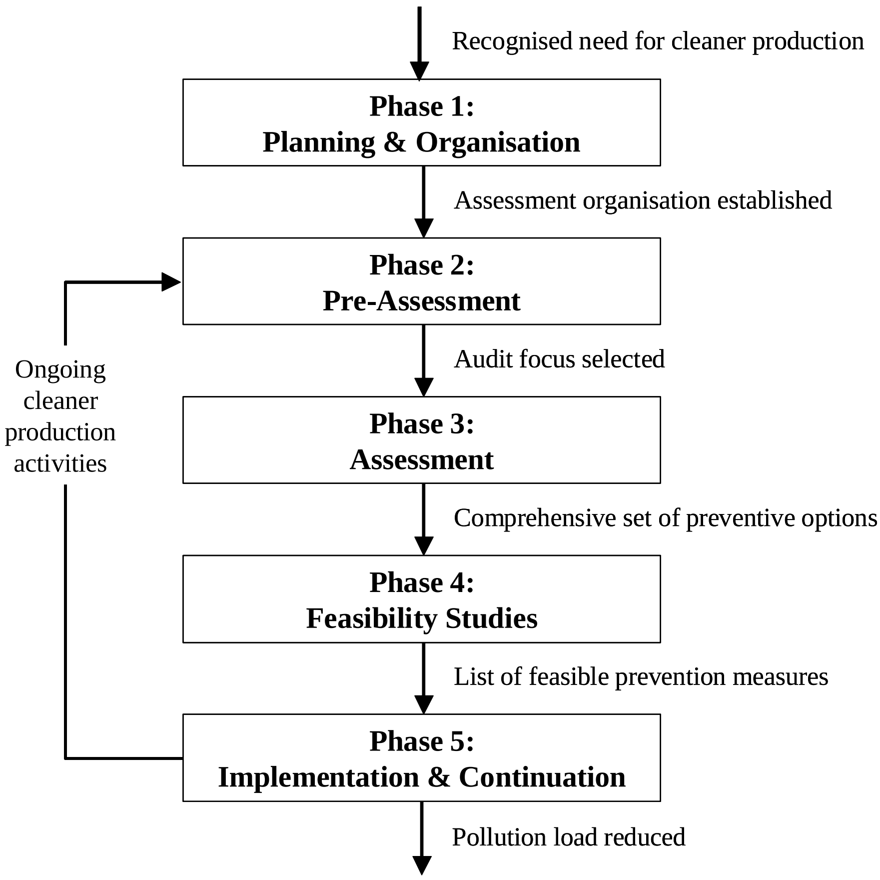

Figure 2.1: Cleaner Production Framework
(de Hoo et al. 2001; UNEP 1994a; Van Berkel 2000b)

Cleaner production focuses on making more efficient use of natural resources (raw materials, energy, and water) and reducing the generation of wastes and emissions at the source. This is generally achieved through - combinations of – five prevention techniques (USEPA 1992):

1. Product modification: change the characteristics of the product, such as material composition and shape. The life time of the new product could be extended, the product made easier to repair, or the manufacturing of the project could be less polluting. Changes in product packaging are generally also regarded as product modifications;

2. Input substitution: the use of less polluting raw materials and the use of process auxiliaries (such as lubricants and coolants) with a long service lifetime;
3. Technology modification: include for example improved process automation, process optimisation, equipment redesign and process substitution;

4. Good housekeeping: changes in operational procedures and management in order to eliminate waste and emissions generation. Examples are spill prevention, improved instruction and training of site personnel; and

5. On-site recycling: the useful application or reuse of waste materials at the same company at which they were generated. External recycling (by another organisation) is generally not considered to be part of the cleaner production concept, because the waste materials leave the company premises and waste generation occurs. Therefore it does not classify technically as waste prevention.

These five prevention techniques are generally not considered hierarchical. However, their preference depends on the specific circumstances at the operation where these techniques are applied. In reality, their preference will depend on the (economic) feasibility of their application. In some cases it may be less expensive to apply good housekeeping (e.g. through employee training and education program). In other cases, it may be more practical and feasible to invest in a technology modification (e.g. flow restrictors, water cascading, insulation). Therefore, the preference or feasibility of a prevention technique has to be determined on a case by case basis.

2.2.3 History of Cleaner Production

2.2.3.1 Internationally

Cleaner production was introduced as a concept by the United Nations Environment Programme (UNEP) in 1989. In September 1990, UNEP held the first seminar on 'Cleaner Production' in Canterbury (UK), to launch the Cleaner Production programme. Since 1990, although its adoption has generally been slow, cleaner production has spread as a viable and preferable environmental management strategy across the world in developed and developing countries. At the UNCED Earth Summit held in Brazil in 1992, cleaner production was woven throughout Agenda 21 and one programme area in particular identified is "Promoting Cleaner Production" (de Larderel 1993).

By the end of 1995, the Cleaner Production Network, sponsored in part by the UNEP initiative, comprised more than 140 Cleaner Production Centres in over 40 countries (de Larderel 1998). The UNEP Industry and Environment Office also initiated training and regional roundtable workshops, and developed an extensive database of cleaner production case-studies known as the International Cleaner Production Information Clearinghouse (ICPIC) (UNEP 1998).

The UNEP meeting in 1998 in Korea formalised an International Declaration on Cleaner Production (UNEP 1999). The declaration calls for action to protect the global environment to include the adoption of improved sustainable production and consumption practices, and to prioritise cleaner production and other preventative environmental strategies such as eco-efficiency, waste minimisation, and pollution prevention. This was in recognition that achieving sustainable development is a collective responsibility. There were over 170 high level signatories for the Cleaner Production declaration in 2000 (UNEP 2000).

2.2.3.2 Western Australia

The uptake of cleaner production (and eco-efficiency) in WA appeared to have lagged behind the uptake in the rest of Australia during the 1990s. Van Berkel (2007c) summarises developments in the promotion and implementation of cleaner production in WA, in four stages: groundwork (1996-1999), experimentation (1999-2002), roll out (2002-2004) and reorientation (2004 onward). WA's remoteness and the dominance of the minerals, energy and agribusiness industries, contributed to the late interest in cleaner production and relatively slow start compared to other parts of Australia and internationally.

Van Berkel states that pioneers in government, industry and academia started to come together in 1998-1999. A concerted effort to define and clarify concepts, strategies and programs, and their subsequent roll out, resulted in a remarkable growth of cleaner production activity in a relatively short period of time. This rapid increase started to level in 2004. This is partially due to external circumstances (e.g. greater competition on the corporate sustainability agenda, drying up of dedicated funding support, the significant growth of the resource sector). In addition, it also appeared that the limits of current cleaner production and eco-efficiency theory and practice have been reached.

According to Van Berkel (2007c), the limits appear to be at least two fold. First, current policies and program designs in WA appear not yet able to achieve a step-increase in the number of businesses involved in cleaner production. Insights from innovation and social marketing theory and practice should be incorporated in the design and delivery of the next generation of cleaner production programs. Second, it appears that mainstream cleaner production tools are insufficiently catered to the technological and organisational complexity of many industries (in WA and globally). Greater engineering and management depth in tools would be required to mainstream cleaner production in routine process design, continuous improvement and change management practices.

2.2.4 Cleaner Production in the Resource Processing Sector

Van Berkel (2007a) notes that the first specific references and interpretations of pollution prevention, waste minimisation, cleaner production, and eco-efficiency in primary minerals and metals production emerged only in the late 1990s (Dharmappa et al. 2000; EA 2000; FWI 2001; Hilson 2000b). Before this time, some early case-studies exist which define environmental management best practice for the mining and minerals processing industry (e.g. ICME/UNEP 1996; Parsons and Hume 1997; UNEP 1991; USEPA 1995), however these do not relate specifically to cleaner production.

Preventative environmental and resource productivity strategies, like cleaner production and eco-efficiency, are not the only means by which the minerals industry can progress sustainable development. Cleaner production should occur in tandem with changes in production and consumption patterns (to dematerialise material (metal) dependent products and services), in collection and recovery of end-of-life metal containing products (to prevent dissipative losses), and in secondary metal production (to maximise substitution of primary metals) (Van Berkel 2007a).

Cleaner production was initially developed and defined with specific reference to the manufacturing and service sectors (EPA 1993; UNEP 1993), which appears to have slowed down its consideration and uptake in the mining and minerals processing sectors. The application of cleaner production practices in minerals processing and metals production can have a positive impact on the composition, leachability, and stability of industrial residues, and is therefore relevant from the perspective of mine closure, site remediation and rehabilitation (Van Berkel 2007b). However, to achieve mine closure with minimal ongoing management requirements, cleaner production in the processing stage needs to be complemented with planned approaches to its closure, storage of large volume wastes, and reduction of acid mine drainage (MMSD 2002; DITR 2006c). A customised framework for the application of eco-efficiency (and cleaner production) is proposed in Van Berkel (2007b). It connects five modified prevention practices (process design; input substitution; plant improvement; good housekeeping; and reuse, recycling and recovery) with five resource productivity themes (resource efficiency; energy use and greenhouse gas emissions; water use and impacts; control of minor elements and toxics; and by-product creation). Van Berkel (2007b) provides a number of case-study examples showing that Australian mineral processing operations can implement cleaner production practices that provide significant environmental and business benefits.

2.3 Industrial Ecology

2.3.1 Theory and Concept

The notion of regional resource synergies (the main theme of this thesis) is rooted in Industrial Ecology. Industrial ecology is by no means a new idea. Attempts have been made to classify and develop the industrial ecology concepts over 30 years; however, these were rather fruitless in terms of gaining momentum and interest from the academic and business arena until the end of the 1980s. One of the most frequently cited articles in the literature of industrial ecology is 'Strategies for Manufacturing' (Frosch and Gallopoulos 1989). This classic document offered the idea that it should be possible to develop industrial production methods which would have considerably less impact on the environment. This hypothesis led to the (re-) introduction of the notion of the industrial ecosystem. In contrast to previous attempts (Hoffman 1971; Gussow and Mevers 1970; Odum and Pinkerton 1955; Hall 1975), Frosch and Gallopoulos' article generated a strong interest for various reasons (Erkman 1997). These include the prestige of the Scientific American, Frosch's reputation in government, engineering and business circles, the weight carried by the authors because of their affiliation with General Motors, and the general context, which had become favourable to environmental issues, and discussions around the Brundtland Commission reports on sustainable development. Although the concepts presented by Frosch and Gallopoulos were not, strictly speaking, original (the concepts were addressed previously by (Hoffman 1971; Gussow and Mevers 1970; Odum and Pinkerton 1955; Hall 1975), the article is seen as the source of the current development of industrial ecology. A detailed historical view on industrial ecology is available from (Erkman 1997).

Although the concept of industrial ecology has been recognised for over 30 years, the theoretical framework of industrial ecology and approaches to advance its implementation are still in their infancy (Harper and Graedel 2004). Therefore there is not yet a single or uniform definition which is universally accepted. (Jelinski et al. 1992) define industrial ecology as ‘a concept in which an industrial system is viewed not in isolation from its surrounding systems but in concert with them’. Van Berkel et al. (1995) state that industrial ecology employs a holistic view to study, assess and improve the utilisation of natural resources (materials and energy) in an industrial society. One of the most authoritative definitions of industrial ecology is provided in Graedel and Allenby (2003):

> *“The means by which humanity can deliberately and rationally approach and maintain a desirable carrying capacity, given continued economic, cultural, and technological evolution. The concept requires that an industrial system be viewed not in isolation from its surrounding systems, but in concert with them. It is a systems view in which one seeks to optimize the total materials cycle from virgin material, to finished material, to component, to product, to obsolete product, and to ultimate disposal. Factors to be optimized include resources, energy, and capital”.*

Industrial Ecology is both ‘industrial’ and ‘ecological’ (Lifset and Graedel 2002). It is industrial in that it focuses on product design and manufacturing processes. Industry is therefore viewed as the primary agent for environmental improvement, as it possesses the technological expertise, management capability and financial and other resources necessary for successful execution of environmentally informed design of products and processes. Industrial Ecology is ecological in at least two senses. Firstly, it looks to non-human ‘natural’ systems as models for industrial activity. Mature ecosystems are extremely effective with respect to resource recycling and therefore promoted as exemplary models for effective recycling in industry and society. Secondly, Industrial Ecology places industry – or technological activity – in the context of the larger ecosystems which support it. This focuses Industrial Ecology on examining the sources of resources used in industrial activity and the sinks that absorb and detoxify the wastes discharged by society.

A simple, but very useful, synopsis of industrial ecology is provided in Jelinski et al. (1992):

§ Industrial ecology is proactive not reactive: Industrial ecology is initiated and promoted by industry because it is in their own interest and in the interest of those surrounding systems with which they interact, not because it is imposed by one or more external factors (such as regulating bodies, community).

§ Industrial ecology is designed in not added on: This characteristic recognizes that many aspects of materials flows are defined by decisions taken very early in the design process and that optimisation of industrial ecology requires every product and process designer and every manufacturing engineer to view industrial ecology with the same intensity that is brought to bear on product quality or manufacturability.

§ Industrial ecology is flexible not rigid: Many aspects of the process may need to change as new manufacturing processes become possible, new limitations arise from scientific and ecological studies, new opportunities arise as markets evolve, and so on.

§ Industrial ecology is encompassing not insular: In the modern international world, industrial ecology calls for approaches that not only cross industrial sectors but cross national and cultural barriers as well.

The four elements above imply that pro-active, flexible, and comprehensive approaches are required for the application of industrial ecology in practical ‘real-world’ situations. Therefore, these elements should be considered carefully when developing effective and customised methodologies to advance regional synergies in the case-study area (the Kwinana Industrial Area).

2.3.2 Industrial Ecology Approaches

Industrial ecology practices can be categorised in the following four approaches (Van Berkel et al. 1995, 1997):

1. The materials specific approach: analyses the way a material flows through the industrial society in order to identify, evaluate and implement improvement opportunities. Numerous examples of such material and substance flow analysis have been conducted for selected metals and materials at various geographical levels: global (Graedel et al. 2004; Graedel et al. 2005), continental (Van Beers et al. 2004, 2003a, 2003b), country (Van Beers and Graedel 2007; Van Beers et al. 2005b), and city (Van Beers and Graedel 2003, 2004). Several techniques can then be applied to improve the materials flows and reduce depletion of the natural resources (e.g. Van Beers et al. 2007a).

2. The product specific approach: analyses the different material flows of the components of a selected product from a system point of view in order to optimise the product-environment interaction. Solutions can be found through life cycle-based design which seeks to reduce the total environmental burden associated with product systems while not compromising on the technical performance, capital and operations costs, quality and consumer expectations (Narayanaswamy et al. 2005; Van Berkel 2000a; Tan and Khoo 2005; Braungarta et al. 2007; Ljungberg 2007; Zwolinski et al. 2006).

3. The actor specific approach: assesses the opportunities and constraints for different actors in industry to change material and product flows in an environmentally-compatible direction. The actors can be divided into three main streams: industries, consumers and government. Within industrial ecology, the primary focus is on industries, because these are the key players in the design and manufacture of products (Frankl and Rubik 2000; Azapagic and Clift 1999; Millet et al. 2007; Huybrechts et al. 1996).

4. The regional approach: focuses on optimising the exchange of materials, energy and information between businesses at the local level. The concept of regional resource synergies (or industrial symbiosis) fits within this regional approach, and is further explained in the following section.

These four approaches are not mutually exclusive, however emphasise different angles from which the industrial society can be influenced in order to contribute to sustainable use of natural resources (Van Berkel et al. 1995). From this categorisation it is clear that the regional synergies concept is one of the subsets of industrial ecology with specific and unique features. Regional synergy development therefore needs customised approaches and methodologies to advance this concept in a meaningful manner.

2.4 Regional Resource Synergies

2.4.1 Overview

Regional synergies are perhaps the best-known application of the principles of industrial ecology. They deal with the exchange of by-products, energy, and water among closely situated firms. Because of the many links between the firms, an industrial area is transformed into an 'industrial ecosystem' or 'industrial symbiosis'. Chertow (2000) defines industrial symbiosis as a process that "engages traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and/or by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity".

The concept of regional resource synergies is closely associated with the clustering of relevant industries based on their services and resource inputs and outputs. Clustering is an important element to allow for the development of regional synergies as well as a mechanism to reduce the need for utility infrastructure and associated costs. Firms and organisations involved in clusters are able to achieve synergies and leverage economic advantage from shared access to information and knowledge networks, supplier and distribution chains, markets and marketing intelligence, special competencies, resources and support institutions available in a specific locality. Industrial clustering focuses on the functional linkages and interdependencies among actors in value chains. In summary, the benefits of industry clustering include (Roberts 2004):

- Attracting businesses to the industrial estate because of the cost benefits associated with co-location and security of resource supply.
- Proximity generates externality savings and economies of scale, which reduce operational costs for companies sharing common suppliers or services.
- It also encourages innovation, which leads to opportunities for the development of new industries especially firms capable of using wastes and by-products.
- The more intense the agglomeration, the greater are the prospects for innovation and synergies.

Several other terms for ‘regional resource synergies’ are used in the literature, including ‘by-product synergy’, ‘by-product exchange’, ‘industrial symbiosis’, ‘eco-industrial park’, ‘eco-industrial network’or ‘industrial ecosystem’ (Lowe and Evans 1995; Lambert and Boons 2002; Klein 2002; Verstegen 2003; Roberts and Wadley n.d.). Depending on the system boundaries, specifics of the project, its management umbrella, or even the geographic location, the above expressions may vary. Regardless of the specific terminology in use, these initiatives have one thing in common: their implementation aims at “creating a system for trading material, energy, and water by-products among companies, usually within a park, neighbourhood, or region” (Lowe 2001). It can be argued that the term regional resource synergies has a wider scope as it also includes the shared use of utility infrastructure and industries which are not located in close proximity. It is recognised that there is no standardised and internationally accepted methodology to define and classify regional resource synergies and related concepts. The field of industrial ecology would benefit from such an initiative; however such a task is not within the scope of this research.

The most often-quoted icon example of regional synergy development is Kalundborg (Denmark) (Ehrenfeld and Gertler 1997; Jacobsen 2003). From an Australian perspective, the Kwinana Industrial Area is a major heavy industrial region with a significant number of successfully operating regional synergies (SKM 2002; Taylor 2002; Van Berkel 2003).

2.4.2 Regional Synergies Classification

Overall, regional synergies seem to fall within three principal categories (Bossilkov et al. 2005; Van Berkel 2003), i.e.:

- Supply synergies: featuring local manufacturers and dedicated suppliers of principal reagents for core process industries (e.g. production of ammonia and chlorine for industrial use).

- By-product synergies: these involve the use of previously discarded by-product(s) (as solid, liquid, or gas) from one facility by another facility to produce a valuable alternative raw material (e.g. recovery and on-selling of carbon dioxide and hydrogen).

- Utility synergies: these involve the shared use of utility infrastructure, and mainly evolve around water and energy (e.g. water recovery and cogeneration).

Supply synergies are not addressed as part of the research as these are 'business as usual', where a business realises 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' which is the distinctive feature of industrial symbiosis (Chertow 2000).

2.4.3 Regional Synergy Development Approaches

It is acknowledged that there are a number of designed and intended approaches available to enhance regional synergy development in industrial regions; these have been applied in various parts of the world subject to the local conditions. In summary, these approaches can be categorised as follows:

- Top-down: The top-down approach includes the active engagement of government agencies in the development of regional synergy initiatives. For example, the eco-industrial park concept has been adopted by the Chinese government adding value to businesses and communities by optimising the use of energy, materials, and community resources. The eco-industrial park approach can assist with achieving greater efficiencies through "economies of systems integration", where partnerships between business meet common service service, transportation, and infrastructure needs (Geng and Yi 2005; Chiu 2004). China has numerous industrial parks under construction in which eco-industrial development principles are incorporated, including Shenjia Chemical Industrial Park and Dalian Economic Development Zone (Geng and Wu 2000).

- Bottom-up: In the bottom-up approach, industries and businesses are the key driver behind regional synergy development. This kind of approach is not pre-planned, not facilitated by a governmental agency or coordinator, and does not include any overall system optimisation studies. The bottom-up approach is rather a result from spontaneous self-organisation. The prime motivation for establishing synergistic relationships is motivated by opportunities for costs savings, or to meet local resource availability limits (Chew et al. In submission). The evolution of industrial symbiosis in Kalundborg is a key example of the bottom-up approach (Chertow 2007). Kalundborg is one of the most published and researched industrial area in terms of regional synergy development (Jacobsen 2003; Chertow and Lombardi 2005; Ehrenfeld and Chertow 2002).

- Sideway in: In the “sideway in” approach government agencies provide an assisting role in regional synergy development, in close collaboration with the targeted industries in a region. An illustrative example of this approach is the establishment of recycling networks in the Styria region in Austria. Inspired by the regional synergy successes in Kalundburg (as outlined above), the Federal Ministry for Environment initiated a research program with regional industries on the creation of innovative solutions for entrepreneurial waste management. An important outcome of the program was the realisation that the communication between industries and authorities is a precondition for successful interpreneurial recycling. As a consequence, the Society for Promotion of Circle Economy, Regional Development and Innovation was formed. This centre focuses on the creation of interpreneurial recycling initiatives with high recycling potential in the region, including used granite, used coating powders, and used wooden pallets (Hasler 2005).

In this PhD research, the cleaner production framework (Figure 2.1) is used as basis for the development of customised methodologies to advance regional synergies in heavy industrial areas. The application of the cleaner production framework aligns best with the ‘sideway in’ approach, i.e. by providing assistance and encouragement to the industries in a heavy industrial area to identify and develop regional synergies. The research reported here was funded through the Centre for Sustainable Resource Processing (CSRP). The CSRP is supported under the Australian Commonwealth Cooperative Research Centres Program. Therefore, this PhD research is indirectly funded from government and industry sources (similar as the ‘sideway in’ approach outlined above).

2.4.4 Current Tools and Methodologies

A review of regional synergy development in sixteen international heavy industrial areas (Bossilkov et al. 2005) revealed that the number of examples of regional resource synergies around the world is growing. The study also concluded that so far the world-wide evolution of regional synergies has been ‘self organising’ as industries pursue business opportunities from collaboration and resource sharing, rather than the result of a structured and planned development. Regional synergies have developed opportunistically in the absence of specific methods for synergy option generation and/or synergy technology selection and assessment. This is despite there being a competency and track record in cleaner production and eco-efficiency methods and metrics and resource recovery technologies, on which such methods could be based (UNEP 1996; USEPA 2001; Crul et al. 1991). There is an opportunity to support the development and implementation of regional synergy projects with customised methods. Continuing to rely on opportunistic synergy development may mean many potential synergy initiatives, and their associated benefits, are missed.

Traditional engineering tools focus on modelling and optimisation of material and energy flows within a process or a facility (e.g. Pinch analysis, Autocad). 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 also the consideration of distance over which the by-product must be transported (typically ignored at the facility level). Despite the existence of some synergy identification tools, Bossilkov et al. (2005) found that their application has been restricted to one or few industrial regions with a limited number of synergy opportunities implemented as a result:

- The predominant type of tool used 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 (mostly in the form of dedicated websites) is widely spread in UK, USA and Canada, and its effectiveness is largely dependent on provided information on the available supply and required demand (No Throw n.d.; Waste Matchers n.d.; Recycler's world n.d.).

- 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 the region around Brownsville, Texas (BCSD-GM 1997) and in a demonstration project in Tampico in the Gulf of Mexico (Young 1999).

§ A spin-off project from the IME tool is MatchMaker!, based in part on the initial work carried out by Bechtel (Brown et al. 1997). It is designed as a materials exchange platform to identify outlets for waste materials based on their generic description. The MatchMaker! Tool focuses on materials rather than on water and energy. The tool has the potential to include industries from a wide geographical area, i.e. "virtual eco-industrial parks". The tool in its original form represents a database framework without data. The creators of the tool acknowledge that the data collection process would be resource extensive, involving industry surveys, site visits, data mining and an extensive literature review.

§ A similar tool was developed by the 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) 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 analysis has been applied in an industrial ecosystem project in the Rotterdam, The Netherlands, where it demonstrated the ability to develop an optimal water use and cascade circulation both within companies as well as in clusters of companies (Baas 1998).

Massard and Erkman (2007) have reported on a method being developed to systematically detect and implement by-product synergies between industrial actors in the Geneva region. A strong focus of their method is industry collaboration and conducting feasibility studies for short-listed opportunities based on an initial preliminary assessment. The method uses a database management tool (Presteo) to treat input-output analysis data and a GIS tool to detect potential industrial partners. The methods are being constantly enhanced. Currently, 19 companies from 10 industrial sectors are involved in the program and approximately 10 are about to join. Potential regional synergies for 17 flows (including energy, water and material flows) are currently being examined for implementation. The method is reasonably consistent with the cleaner production framework. The tools developed as part of this research do not seem to be applicable to the Kwinana case-study because the research focuses on small and medium sized enterprises located in a wider metropolitan area, and not on heavy industries in a confined industrial area (the topic of this thesis).

Generally, little variation exists between the methodologies used for regional synergy projects (Young 1999; Brown et al. 1997; Industrial Economics 1998; Nobel 1998; Baas 1998; Bossilkov et al. 2005). Most projects tend to take stock of the existing and possible synergetic opportunities, i.e. developing status quo case studies, with no intention for further progress (Venta and Nisbet 1997; Schwarz and Steininger 1997; Homchean 2004). Overall, the main components of any synergy development methodology should at least include (adapted from Bossilkov et al. 2005):

- Awareness and recruitment: seeking support and commitment of a core group of participant companies;

- Data collection: to account for each company's in-flows and out-flows of materials, commodities and utilities. This phase generally uses a survey instrument, usually followed by an on-site visit or telephone interview;
- Analysis / synergy identification: Usually the data is entered into a database of some format. Initially a large number of rough matches are identified as a starting point. Facilitated brainstorming meetings (numbers vary between projects) are organised to either screen the recognised synergies or to identify additional ones; and
- Implementation and continuation: through further meetings to prioritise projects and develop an action plan for implementation of viable synergies.

2.5 Linking Cleaner Production, Industrial Ecology, and Other Concepts

Cleaner production and industrial ecology are related to several other environmental management concepts. The figure below presents the relative position of key environmental concepts in terms of environmental impact covered, primary motivation driving the concept, reactive or preventive nature of the concepts, and core focus.

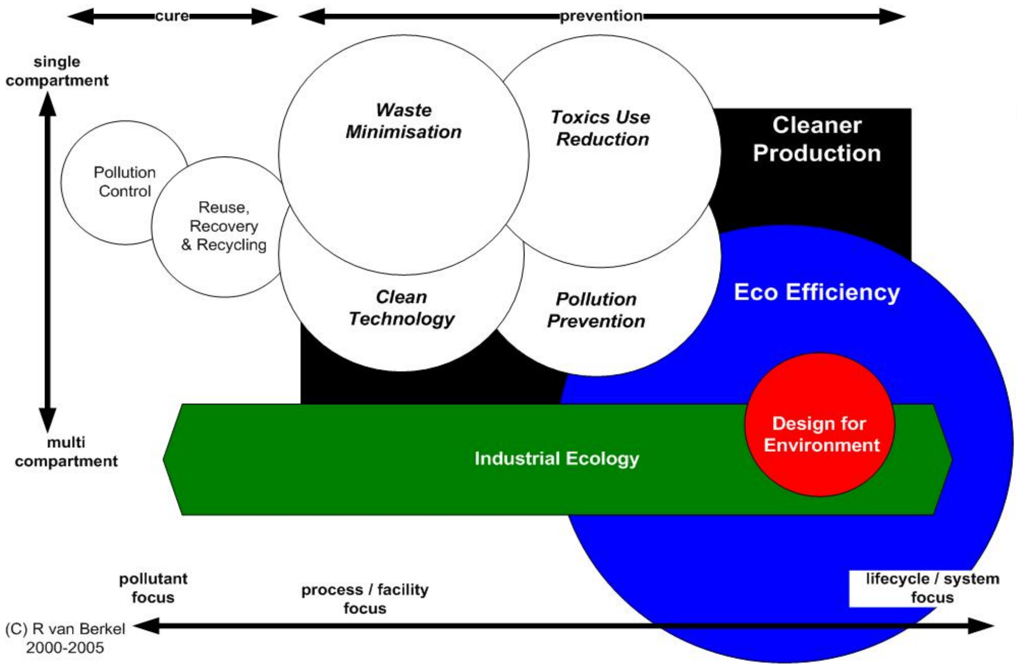

Figure 2.2: Concepts Related to Cleaner Production and Industrial Ecology (Van Berkel 2006b)

According to Figure 2.2, the classic approaches (such as pollution prevention and toxics reuse reduction) tend to focus on one key environmental impact only, rather than the full spectrum of environmental impacts (like cleaner production, and industrial ecology). The newer preventive approaches explicitly target reduction of environmental impacts throughout the product's life cycle, by focusing on product design (design for environment) or on approaches for value adding activities (eco-efficiency).

Cleaner production has significant overlap with eco-efficiency. This latter concept has been initiated and developed by the World Business Council for Sustainable Development (WBCSD). The WBCSD (1996) defines eco-efficiency as "the delivery of competitive priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life cycle, to a level at least in line with the earth's carrying capacity". The WBCSD identified seven key components of eco-efficiency: reduce material intensity of goods and services, reduce energy intensity of goods and services, reduce toxic dispersion, enhance material recyclability, maximise sustainable use of renewable resources, extend product durability, and increase the service intensity of goods and services (DeSimone and Popoff 1997). Implementation of these eco-efficiency components will most often call for practical changes that fall under one of more of the prevention practices of cleaner production: product modification, input substitution, technology modification, good housekeeping, and on-site recycling (see Section 2.2.2). On the other hand, implementation of these prevention practices will also achieve one or more of key components of eco-efficiency. Therefore, eco-efficiency and cleaner production are truly complementary concepts, with eco-efficiency focusing on the strategic side of the businesses ("value creation") and cleaner production on the operational side ("production") (Van Berkel 2000b).

Figure 2.2 also shows that there is a strong link between the concepts of cleaner production and industrial ecology. Both concepts have a focus on prevention of environmental impacts, although industrial ecology also covers end-of-pipe treatment (cure). Cleaner production can be driven by both regulations and businesses seeking to enhance their business performance. Industrial ecology practices are mostly driven by business, and only influenced to a limited extent by regulations. The system boundaries for industrial ecology and cleaner production often differ. Cleaner production activities are mostly focused at the firm level, but the system boundaries can expand when the company starts to demand preventative activities from their suppliers and product designers. Industrial ecology, by definition, focuses on the interconnectivity of industrial actors as part of a wider system and promotes actions at the regional or industrial level. As explained earlier in this literature review (Section 2.3.2), the regional synergies concept is a sub-set of industrial ecology (regional approach).

2.6 Barriers to Implementation of Resource Efficiency Initiatives

Although resource efficiency initiatives make sense from an environmental and material savings perspective, the implementation of these initiatives is subject to a number of barriers. These need to be understood and considered in order to drive forward resource efficiency projects with businesses.

In a general sense, the literature indicates that the following barriers apply to the implementation of resource efficiency initiatives (Moors et al. 2005; Hilson 2000a; Shi et al. 2008; Mitchell 2006):

§ Economics: Any resource efficiency project will have to compete with other investment projects which may have better return on investments. The challenge for resource efficiency projects is therefore to apply low cost beneficiation processes; otherwise it may be difficult for the business case to compete with other potential investments. Furthermore, resource efficiency initiatives result in savings in raw material consumption and reduced amounts of wastes going to landfill. The incentive to optimise these elements is largely determined by the raw material costs and landfill costs. In Western Australia, the costs for water, energy, and landfilling are relatively low (although these costs are increasing). This poses a significant barrier to build up a sound business case to increase resource efficiencies.

§ Supply chain and production system: Significant interrelationships and interdependencies can exist in the supply chain of a product (e.g. resource extraction, energy generation, manufacturing of products and by-products, use of recycled materials, and the treatment of wastes and emissions). These interdependencies result in complex industrial production systems. Certain industries (in particular in the mining and resource processing sector) have long-term contracts with their suppliers and customers, or they are part of a larger technological alliance with other industries. These features tend to keep the industries in their traditional production pattern, rather than implementing new resource efficient technologies or other cleaner production practices which would affect other players in the supply chain (Moors et al. 2005).

§ Knowledge and technology: Smaller and medium-sized industries often have small research and development departments. These are often focused on troubleshooting and process optimisation in terms of production and return on investments. These industries do not necessarily have an extensive inter- and intra-firm knowledge network for the development and exchange of scientific and technical know-how about more resource efficient or (cleaner) production methods and technologies. Research and developments in new (more resource efficient) technologies are generally carried out by the large national and international industries (Moors et al. 2005). This poses a barrier to the implementation of new technologies by the "smaller" players in the respective industry sector.

§ Legislation: There are known cases (notably in the case-study region of this PhD research) where industries face obstacles in obtaining governmental approvals for resource efficiency initiatives (e.g. use of alternative fuels and reuse of by-products). Even if some resource efficiencies are techno-economically feasible and have positive economic, environmental, and social impacts, their practical implementation have in some cases been halted by uncertainties in the legislative framework, in particular with regard to the final responsibility for approved reuse options, and community (mis)perceptions (Van Beers et al. 2009).

§ Company culture: Leadership and commitment from senior company management is required to trigger the investigation and subsequent implementation of resource efficiency initiatives. Conservative and established management styles affect all levels of the organisation. This can pose a significant barrier to process innovations and the implementation of new (more resource efficient) practices and technologies. Furthermore, company culture also influences the understanding and appreciation of the broad range of benefits gained by the implementation of resource efficiency projects other than return on investment (e.g. security of water and energy supply, community support, long-term license to operate, less waste to landfill).

From a networking perspective, it is stipulated that companies can realise environmental and economic benefits by working together as opposed to acting individually (Van Beers 2000). Without addressing and overcoming "networking" barriers, it is unlikely that identified co-operative solutions to improve their overall resource efficiencies and environmental performance will be implemented. According to (Coleman 1994; Côté 1994; Lichtenstein and Hoeveler 1996; Tang et al. 1999), the barriers for networking of businesses can be summarised as:

- § There might be limited trust amongst network partners which does not encourage businesses to work together with each other (trust).
- § Network partners might compete in the same market which limits the willingness of a company to establish partnerships with its competitors, especially if the market conditions are tight (competitiveness).
- § There can be a possible conflict in commercial interests amongst network partners (conflict in interests).
- § Co-operative solutions may require a change of thinking or working methods; these changes concern cultural changes which are often hard to achieve (change of culture).
- § Certain co-operative solution might require the exchange of confidential information or trade-secrets (confidentiality).
- § There is a reluctance to depend on others, companies prefer to be fully in-control themselves (dependency).
- § There is a level of uncertainty involved as certain tasks are given out-of-hand (uncertainty).

The above outline the barriers to resource efficiency and collaborative industry projects in a general sense. Further in this thesis (Section 4.4), the author presents a detailed comparative review of the drivers, barriers, and triggers for regional synergy developments in the case-study area (Kwinana Industrial Area). This assessment will provide further valuable lessons for the development of customised methodologies to advance inorganic by-product synergies (Chapter 6), water utility synergies (Chapter 7), and energy utility synergies (Chapter 8).

2.7 Sustainable Resource Processing

Sustainable development is a pattern of resource use that aims to meet human needs while preserving the environment so that these needs can be met not only in the present, but in the indefinite future. In 1987, the term was coined by the Brundtland Commission in the report 'Our Common Future' (WCED 1987). It has since become the most often-quoted and internationally recognised definition of sustainable development:

> *"Sustainable Development meets the needs of the present without compromising the ability of future generations to meet their own needs." (WCED 1987)*

It is generally accepted that the dimensions of sustainability are: environmental, social and economic, also known as the "three pillars of sustainability" (UNGA 2005). These pillars are not mutually exclusive, but can be mutually enforcing, as shown in Figure 2.3.

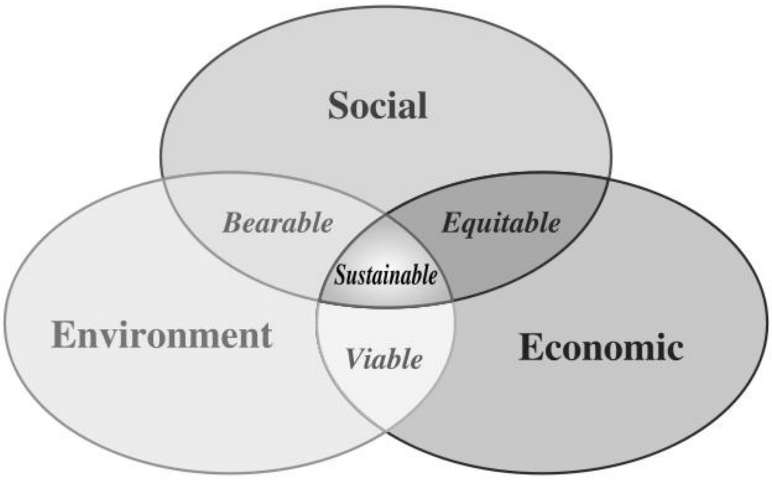

Figure 2.3: Three Pillars of Sustainability (Adams 2006)

It is outside the scope of this research to extensively investigate the meaning, vision, and implications of sustainable resource processing. The author recognises that this is a PhD topic in itself. The aim of this research is to develop customised methodologies that will assist with the identification and implementation of regional synergies in heavy industrial area, and thereby contribute to enhancing the sustainability of the industries at a regional level. It is the author's view that sustainable resource processing will have to meet the definition of sustainable development as defined by the Brundtland commission, and that 'sustainable resource processing solutions' should have to comply with the three pillars of sustainability. The author does not claim that regional resource synergies will create a 'sustainable business'. Regional synergies should be regarded as *one of the avenues* to progress towards more sustainable resource processing, mainly through increasing resource efficiencies and reducing wastes and emissions. The discussion below illustrates the multi-faceted agenda of sustainability and the resource processing sector in Australia.

Australia is unique among industrialised economies for its degree of dependence on the mining and minerals sector. The direct contribution of minerals to GDP was around 9% during the 1990's and has increased since then. In 2000, Australia was among the top three producers of 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 throughout 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 metals such as gold or base metals) and/or in heavy industrial complexes (for minerals such as 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 to compliance and beyond-compliance initiatives which offer competitive advantages.

The resource processing industry is an intensive and large scale user of water and energy (Norgate and Lovel 2006; CSRP 2007b, 2007a). Minerals processing and metal production is 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 (see e.g. Algie 2002; Norgate et al. 2006; Stewart and Petrie 2006).

On the positive side, metal recycling is well established, allowing a large proportion of all metals produced to remain in use for multiple use cycles (e.g. ICMM 2006). Secondary metals production has multiple benefits over primary metals production. The metal value is preserved, mining of ore is avoided and secondary metals production is less energy intensive than primary metals production. However, there are fundamental restrictions to metal recycling which pose an upper limit of how much of the metal from an end-of-life product can be recovered and recycled as a secondary metal (Reuter et al. 2005; Verhoef et al. 2004).

It is widely accepted that economic development should be pursued in tandem with social advancement and environmental protection and management. Overall, sustainable resource processing is concerned with finding ways to progressively and systematically eliminate wastes and emissions in the metals and minerals cycle, while at the same time enhancing business performance and meeting community expectations (Herbertson and Sutton 2002; Van Berkel and Narayanaswamy 2004). Over the past two decades there has been much debate about the implications of sustainable development for the resource processing sector (e.g. Cowell et al. 1999; Hilson and Murck 2000; MMSD 2002; PWC 2001; Whitmore 2006). Some argue that mining of non-renewable resources can not be part of sustainable development, while others are more concerned with the ultimate fate and potential accumulation in the environment of the mined materials, and their by-products, and the energy requirements for metal production (Robert 2003; Van Berkel 2007b). In light of social and economic development, it must be acknowledged that minerals and metals are currently indispensable for supplying the world with the goods and services which enable our modern lifestyle (DITR 2006b; ICMM 2006).

From the above discussion, it is clear that the sustainable development agenda for the resource processing sector is multi-faceted, and includes dematerialisation, design for disassembly and recycling, optimisation of end-of-life product recovery and recycling systems, and environmental innovations in primary metals production (Van Berkel 2007a). This thesis evaluates the contribution of regional resource synergies to sustainable development of resource processing industries at the regional level by increasing resource efficiencies and reducing wastes and emissions. The KIA is

Western Australia's most diverse and concentrated industrial region with resource processing industries. Therefore, the KIA has been selected as the case-study area for this research. A detailed description of the KIA is provided in the next section.

2.8 Kwinana Industrial Area (Case Study Area)

2.8.1 Overview

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 industries are concentrated in a few industrial areas, of which the Kwinana Industrial Area is by far the largest and most diverse. Kwinana is located 40 kilometres 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 4,800 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$15 billion annually (SKM 2007). Overall, the KIA plays a very important role in the economy of Western Australia, and in the local community. The region has long been recognised as a cornerstone of the Western Australia's economy.

The KIA was established in the 1950's following a special Act of Parliament, which secured an area of approximately 120 square kilometres to accommodate the development of major resource processing industries in Western Australia. This sparked the beginning of the State's first major industrial complex. The BP oil refinery commenced production in 1954, followed soon by a steel rolling mill in 1956 (now closed down), an alumina refinery in 1964, a blast furnace (now closed down) and ammonia, nitrate, fertiliser plants in the late 1960's, a power station and a nickel refinery in 1970, and a bulk grain terminal in 1976 (DTF 2004). Manufacturing peaked at around 46% of total State primary, mining and manufacturing production in 1963-64, before the iron ore boom in the north of the State reduced its relative importance (DTF 2004). In the early 1990's further development took place with the establishment of agricultural chemicals sites, two chlor-alkali plants, cyanide production plants, LPG extraction plant, a second air separation plant and a titanium dioxide pigment plant. The KIA continued to grow with the new import/export terminal in 1992, oil and chemical storage and tanker facilities and a direct reduction iron making process development facility in 1993, fused zirconia works, flocculant plant and cogeneration plants in 1996-97 and further extensions of various industries, predominantly inorganic chemicals, as well as the recent construction of a commercial scale direct iron making plant and a combined cycle gas-fired power station.

The KIA is home to a diverse range of mineral processing and other heavy industries. These include (SKM 2002): 2,000 kt/yr alumina refinery (Alcoa), 70 kt/yr nickel refinery (Kwinana Nickel Refinery), 105 kt/yr titanium dioxide pigment plant (Tiwest), 850 kt/yr lime and cement kilns (Cockburn Cement), 135,000 barrels/day oil refinery (BP), and 800 kt/yr pig iron plant (HIsmelt). These are complemented with a variety of chemical producers, including CSBP (ammonia, ammonia nitrate, cyanide, chlor-alkali and fertiliser plants), Coogee Chemicals (inorganic chemicals), Nufarm (herbicides and other agricultural chemicals), Nufarm Coogee (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 of Verve Energy, two cogeneration plants (116 MW (Kwinana Cogeneration Plant) and 40 MW (Verve Energy) respectively), 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). There is historically considerable supply chain integration between these industries in the area. A number of companies produce essential raw materials for the manufacturing and refining processes or other nearby enterprises. Figure 2.4 provides an overview of the location of companies in Kwinana.

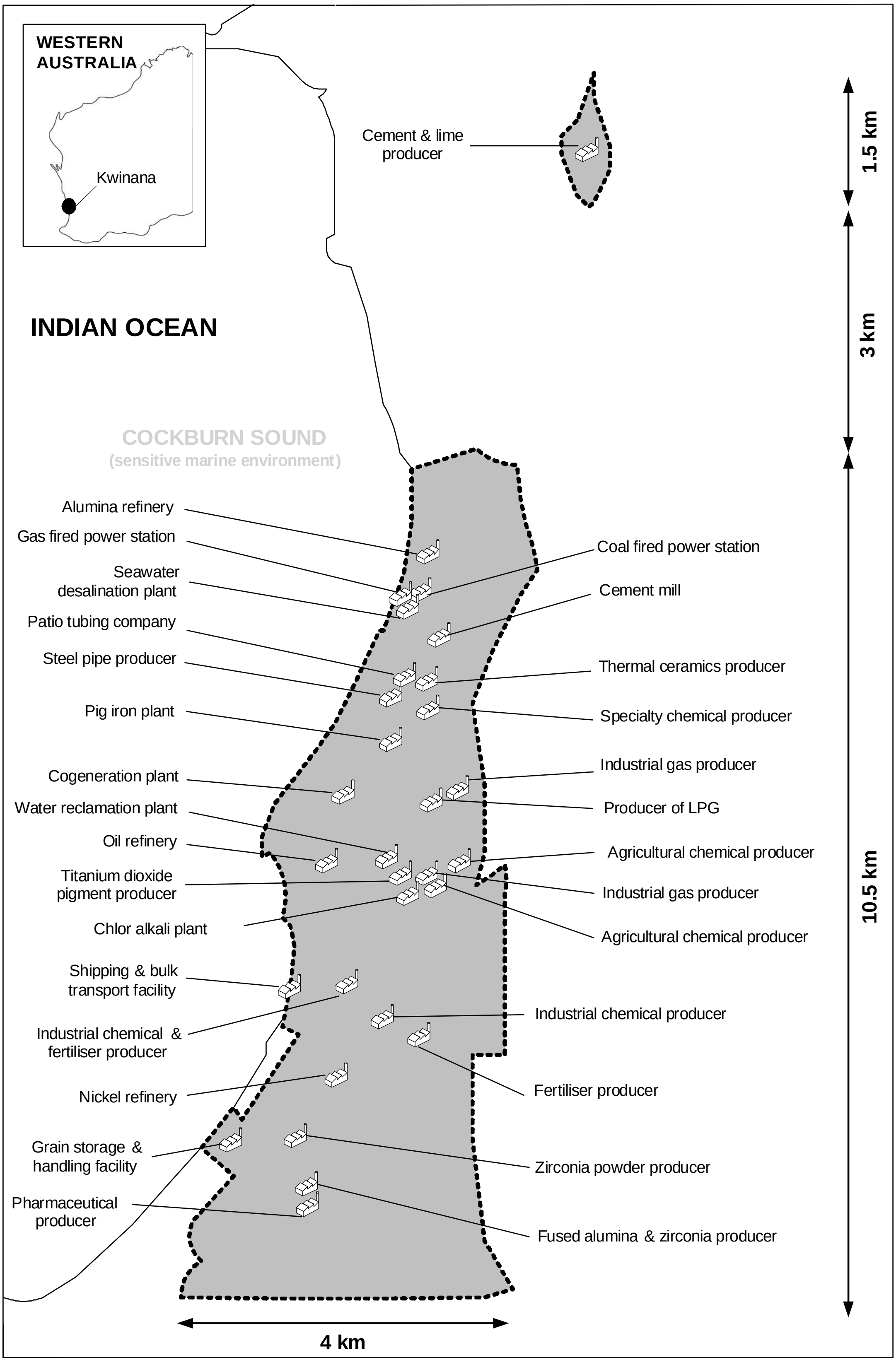

Figure 2.4: Location of Main Process Industries in the Kwinana Industrial Area (Van Beers et al. 2007b)

2.8.2 Kwinana Industries Council

In 1991 the core industries established the Kwinana Industries Council (KIC). Prior to this there was no formal industry association for the KIA. The original purpose of the KIC was to organise 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 to foster positive interactions between member companies, government, and the broader community. The KIC is now an incorporated business association with membership drawn from all the major industries and many of the smaller businesses in the KIA (KIC 2005).

The protection of the environment is a key priority of the KIC and efforts concentrate on industry minimising its impact in the following areas (Swetman et al. 2006):

- Air quality;
- Water quality including groundwater and Cockburn Sound;
- Cumulative noise and vibration;
- Contaminated sites and waste management;
- Visual amenity;
- Transport and infrastructure.

The KIC works closely with its members, appropriate researchers and other contributing stakeholders to develop innovative methods to deal with by-products and waste in the KIA by identifying and investigating opportunities for Kwinana industries where environmental, public health or financial benefits can be realised through:

- Improved materials and energy efficiency;
- Reduced waste and emissions through recycling, adoption of new technologies and practices and identification of synergies;
- Enhanced value creation;
- Promotion of sustainable development principles, leading to improved sustainability.

Geographic proximity and industrial diversity have turned the KIA into a world class example of regional synergies providing environmental benefits to the community beyond that which can be achieved by widely dispersed industries. For this reason, the KIC is keen to promote the advantages of interdependence, or connections, between industries and to examine opportunities to increase the number of regional synergies. Members of the KIC are committed to expanding the level of synergies in the KIA to increase competitive advantage, environmental and community benefits.

2.8.3 Regional Synergies

Based on the desire of the local industries and the State Government to understand and document the full economic and social contributions of the KIA, 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 2007 (SKM 2007) and used the findings of similar studies undertaken earlier (SKM 2002; Dames & 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 2005, the number of core process industries in Kwinana increased from 13 to 21, and the number of existing interactions increased from 27 to 145 (including 91 between core process industries and 54 with service and infrastructure industries). Each interaction represents either transfer of product(s), by-products or commercial cooperation.

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 Curtin University of Technology (as a core participant in the Centre for Sustainable Resource Processing). Opportunities have since been pursued by the KIC in four areas: large volume inorganic process residues (e.g. fly ash, bauxite residue, gypsum), non-process 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 amongst companies), and water conservation.

The often-quoted icon example of regional synergy development at Kalundborg (Denmark) illustrates the benefits of regional synergies (Ehrenfeld and Chertow 2002). From an Australian perspective, Kwinana is a major heavy industrial region with a significant number of successfully operating regional synergies (SKM 2002) (Van Beers 2007). The synergies already in place in Kwinana are quite diverse. Regional synergies have truly taken off since the late 1980s, providing economic, environmental and social benefits, and making Kwinana a world leading example of regional synergy development. The existing synergies were developed in response to perceived business opportunities and environmental and resource efficiency considerations. Further background information on the existing synergies in the KIA is provided in Chapter 4.

The existing synergies in the KIA have developed since the establishment of the industrial area in the 1950s. Initially, the evolution of regional synergies in the KIA has been ‘self organising’ as industries pursued business opportunities from collaboration and resource sharing, rather than the result of a structured and planned development. Despite a high number of existing synergies in Kwinana, it appears that only direct reuse opportunities available through relatively well established technologies (e.g. heat exchange, water reuse technologies and cogeneration) have come to fruition. This implies that even though Kwinana is well positioned as an example of international best practice in regional synergies, outstanding organisational and technological challenges seem to have prevented many other opportunities from being realised. It appears that the “low hanging fruit” opportunities have materialised in Kwinana. There is significant potential for the identification and implementation of more challenging synergy opportunities which can result in significant sustainability benefits. It is anticipated that a structured and coordinated approach (for example, based on the cleaner production framework (Figure 2.1) would lead to the identification and development of further synergy opportunities.

2.8.4 Priority Areas for Regional Synergy Development

Key priority areas for advancing sustainable development through regional synergies (by increasing resource efficiencies and reducing wastes and emissions) in the KIA are:

- Inorganic by-products: There are significant volumes of inorganic process by-products in the Kwinana area, from current operations as well as being stockpiled from past operations (e.g. bauxite residue, fly ash, kiln dusts, gypsum, and iron making slags). Their utilisation as valuable by-products will significantly reduce liabilities associated with current management and storage practices, and will therefore make a significant contribution to the sustainability of the KIA. The opportunity exists to replace virgin materials with recovered inorganic by-products from industrial operations in Kwinana, either directly or after beneficiation to improve properties, in construction and engineering, sustainable agriculture, minerals and metals production and other applications. Although recovery opportunities have to some extent been evaluated for each of the main inorganic by-product streams, their realisation has not yet materialised on a significant scale.

- Water: Water consumption and effluent disposal by the Kwinana industries are key environmental issues addressed by the KIC. Over the past two decades significant progress has been made towards the improvement of water consumption and disposal, both at company level (e.g. on-site water efficiency assessments at various KIC member companies) and at regional level (e.g. Kwinana Water Reclamation Plant). Individual companies had achieved major water savings prior to engaging in water synergies, e.g. Tiwest Pigment Plant, CSBP, and BP Refinery (DEH 2001a, 2001b; WASIG 2005). Due to declining levels of groundwater and stored water in Perth Metropolitan dams, fresh water is likely to become an increasingly scarce resource over the next decades and the cost of water is likely to increase over time. Runoff into dams has reduced by 40-50% since 1975 due to decreased rainfall. The State Water Strategy includes a water reuse target of 20% by

2012 (GoWA 2003). Hence there is an urgent need to further investigate the opportunities for enhancement of water efficiency and reduced effluent disposal in the KIA due to declining water supplies in the future, increasing external pressure from government and other stakeholders, and anticipated expansion plans for Kwinana.

§ Energy: The discharge of waste heat is a significant source of energy loss in many Kwinana operations using hot processes, utilities and/or process equipment. The KIC and its industry members recognise that energy consumption and energy releases from industrial operations are key environmental issues. Progress has been made towards the improvement of energy efficiency and recovery in the KIA, both at the company level (e.g. on-site energy efficiency assessments) and also through regional synergies (two cogeneration facilities). However, there remains a need to further investigate the opportunities for enhancement of energy efficiency and recovery due to increasing external pressure from government and other stakeholders (mandatory energy opportunity assessments for large industrial users (>0.5 PJ/yr)), climate change policies, and potentially a carbon trading scheme. There are also developments with regard to (low grade) energy recovery technologies and process intensification and integration concepts that provide greater and more diverse technical opportunities for energy recovery. Therefore, it is pertinent to assess the technical, economical, and environmental potential of energy efficiency and recovery opportunities in the KIA.

2.9 Water-Energy Nexus

Water-energy nexus is the recognition of the depth of the links between the two industries (Marsh 2009). The transportation and treatment of water are energy consuming processes. Furthermore, energy production (e.g. electricity generation) is a water consuming process. Both water and energy are closely connected and inter-related, as illustrated in the paragraphs below.

In summary, energy is consumed at five stages of the water cycle (Cohen 2007):

- Extracting and conveying water: the pumping water from aquifers, rivers and potential other sources (seawater), possibly over hills, into storage ponds;
- Water treatment: pumping and processing of water to meet the quality standards of the intended end-use (e.g. drinking water, industry feedwater);
- Water distribution: pumping and pressuring the water, possibly through gravity pressurisation and distribution when reservoirs are sufficiently higher than the location of the water user;
- Water consumption: additional energy is used through various means such as treatment of water with softeners, circulation and pressurising water with circulation pumps and irrigation systems, and the cooling and heating of water (e.g. air conditioning);
- Collection and treatment of wastewater: wastewater is pumped to the treatment plant where it consumes further energy to treat water to discharge or recycling quality standards through aeration, anaerobic digestion, and/or other treatment systems.

On the other hand, large volumes of water are used in energy production. (Larson et al. 2009) researched the quantitative water requirements for electricity generation. The work illustrated that the water input steps varied for the different means of electricity generation (e.g. fossil fuels, renewables, hydro and nuclear, and geothermal), but generally included agriculture, mining, transportation, makeup water, processing, cooling, cleaning, and evaporative losses. For example, electricity generation from coal water is required at various stages of the process, including extraction (mining), processing (washing), fuel conversion (gasification), and cooling.

In developing the customised methodologies to advance water and energy utility synergies, it is important to consider the water-energy nexus where possible and appropriate. It is envisaged that the during the business case evaluation of promising water utility synergies, the associated increases in energy consumption are incorporated as well, and visa versa with promising energy utility synergy opportunities.

2.10 Critical Analysis of Theory, Practice, and Tools/Methodologies

2.10.1 Cleaner Production and Industrial Ecology

A critical review of the two concepts (e.g. Hirschhorn 1997) claims that both cleaner production and industrial ecology are weaker pollution prevention variations. Cleaner production has less pollution prevention integrity as it includes internal recycling as one of its prevention mechanisms. It is argued in (Baas 1998) and (Hirschhorn 1997) that industrial ecology tends to have an even higher potential for diffusion of the pollution prevention principles as industrial ecology includes off-site recycling and waste treatment. Even so cleaner production is an established concept for decades, there is discussion about its exact definition. Some argue that cleaner production only includes process, product and material changes that reduce pollution at the source. Others argue that cleaner production and pollution prevention also cover other forms of recycling such as off-site recycling of waste streams by specialised industries. For example, according to the Chemical Manufacturers Association the hierarchy of pollution prevention practices includes source reduction, recycling, and energy recovery, and waste treatment (Association 1994).

Industrial ecology can be regarded from two perspectives, either as an incremental extension of efficiency improvements underway in industry, or as a radical new concept that should be embraced as the overarching concept to incorporate sustainable development principles into industrial development (O'Rourke et al. 1996). It is argued that current and future discussions on the definition, boundaries, and practice of industrial ecology assist with the evolution of the theory and practice in the academic and industrial arena. The same happened to pollution prevention and cleaner production which developed, over a time period of over 10 years, from a concept to a proven and practical means to assist industries with enhancing their environmental performance (Oldenburg and Geiser 1997).

A comprehensive review of the differences and similarities between industrial ecology and cleaner production (pollution prevention) is provided in (Oldenburg and

Geiser 1997). A summary of this review is provided in Table 2.1. From the review it is clear that despite that their differing origin, concept principles, and current state of development, industrial ecology and cleaner production are similar in various ways. Both cleaner production and industrial ecology promote the reduction in the volume of pollutant discharges to the environment, and both require material flow information to measure performance. One of the most significant differences is around the system boundaries. While both concepts strive for production efficiencies and improvements, the main focus of cleaner production is on achieving efficiencies in industrial and commercial processes or within one company, while industrial ecology takes a broader systems perspective to tackle environmental issues.

Table 2.1: Differences and Similarities between Cleaner Production and Industrial Ecology Modified from (Oldenburg and Geiser 1997)

	Cleaner Production	**Industrial Ecology**
Differences	Primary goal is pollution prevention and reduce risks	Primary goal is optimisation of resource flows and promote sustainability
	Primary focus is on individual firms	Primary focus is on the whole systems approach of business networks
	Role of recycling include only in-process (internal) recycling	Role of recycling includes in-process (internal), off-site (external) and between firms
	Role of government is primarily to provide technical assistance	Role of government extends to removal of regulatory barriers
Similarities	Both concepts promote life cycle assessment as a strategic tool	
	Both promote reduction in the volume of pollutant discharges to the environment	
	Both require material flow information to measure performance	
	Both use many of the same analytical methods to determine and choose among options (e.g. life cycle assessment)	

Overall, it is the opinion of the author of this thesis that cleaner production has a strong focus on the prevention of the generation of wastes within individual industries (in line with definition of UNEP provided in Section. 2.2.1). As outlined earlier in this thesis (Section 2.3.1), there is not yet a standard and uniform definition for industrial ecology. However, the unifying element in industrial ecology is its core focus on the optimisation of the industrial ecosystem as a whole includes the transformation of “wastes” (e.g. by-products, wastewater, waste heat) into other useful and valuable resources (external recycling of “wastes”).

It is the author's opinion that the field of industrial ecology and cleaner production would benefit from focused and applied approaches and discussions on how to advance the two concepts in real-life situations in close collaboration with the industry sectors and other stakeholders (e.g. government). This is more important than being drawn into deep philosophical discussions and attempts to capture and summarise all academic opinions and highly complex theoretical models that are currently being published in journals and at conferences. It is of key importance for the academics to communicate in the language of the industries and policy makers who should be regarded as the client of the research work. Without this, the research will not have the impact that is needed or get the attention it deserves to make substantial 'sustainability' improvements.

2.10.2 Industrial Ecology

From the literature review, it is clear that the concept and theory of industrial ecology remains mostly untested or untried in practical real-world circumstances. The main focus of recent and current regional synergies research internationally is on knowledge building, studying historical developments, and examining existing synergies (Jacobsen 2006; Ehrenfeld and Gertler 1997; Desrochers 2004). Research on the development of new regional synergies, which provide business and sustainability benefits to the region and industries involved, remains scarce (e.g. (Dias and Yates 2001; NISP 2004; GTZ 2000). In contrast, the cleaner production concept has a proven track record in delivering business benefits and enhancing the environmental performance of industries. There are abundant case-studies in the public domain which showcase the benefits, costs, practicability, lessons learnt from the application of cleaner production (Oldenburg and Geiser 1997). Industrial ecology is a relatively new concept which has only been extensively researched for the last 15 years. The field began by conceptualizing industrial systems and has now made the transition to gathering the data that characterize such systems (Harper and Graedel 2004). One of the greatest challenges that industrial ecology now faces is applying the knowledge gained from these efforts in real-world situations. Industrial ecology needs to move forward on its path to maturity by using the results of these initial analyses to stimulate the evolution of existing industrial ecosystems and to influence the development of new industrial ecosystems - all with the overarching goal of industrial sustainability.

This view that the industrial ecology concept still lacks in practical application is shared by (Ehrenfeld 2004). It is noted in this article that industrial ecology must expand its legitimacy beyond the academic world if it is to gain a foothold in other domains. It appears that this key aspect of the institutionalisation process has not occurred or is happening at a very slow pace. The largest proportion of publications on industrial ecology comes from academia, with only a very small proportion from industry, government, or other sectors. Ehrenfeld argues that more work is demanded to demonstrate the benefits of bringing industrial ecology into the everyday world of business. If industrial ecology does not emerge out of academic studies without a direct application in industry, industrial ecology may become strongly criticized as mere ‘wishful thinking’.

2.10.3 Best Practice Review of Regional Synergies

A detailed review of best practices of regional synergy development from around the world (Bossilkov et al. 2005) 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 heavy industrial areas. In addition, the study also exposed the lack of attention given to technological and engineering challenges specifically associated with regional synergy development.

In the best practice review (Bossilkov et al. 2005) it was observed that recent activities in terms of ongoing efforts for identification and further implementation of synergy opportunities is evident in less than one third of the industrial regions reviewed. In two-thirds of the case-studies internationally, despite likely good intentions, there has been no follow-up. The process for identification and evaluation of potential synergies in an 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, feasibility analyses, and/or implementation. The ongoing assistance to the industries with the evaluation and development of promising opportunities is of crucial importance to result in successfully implemented synergy projects. Without rigorous, systematic and practical methodologies to regional synergy identification, development and implementation, it is likely that potential opportunities would be missed (Van Beers et al. 2007c).

The majority of the synergies identified worldwide included uncomplicated exchanges, with little or no processing or treatment of the by-products. Therefore it appears that current efforts globally only identify a limited number of potential opportunities. Therefore, a comprehensive and industry-focused approach is required to encourage and advance the process for regional synergy development. There is evidence that a committed approach to industrial synergies ultimately brings both economic and environmental benefits to the industries and communities involved (Bossilkov et al. 2005; Taylor 2002; Massard and Erkman 2007; CECP 2007).

2.10.4 Comparative Review of Tools and Methodologies

Table 2.1 provides a comparative analysis of available tools and methodologies which can assist with the identification and development of regional synergies. This includes customised methodologies based on the proposed cleaner production framework (Figure 2.1). This framework is central to this thesis, and includes five stages (planning and organisation, pre-assessment, assessment, feasibility studies, and implementation and continuation). It represents a proven pragmatic and constructive approach to assist industries with the identification, evaluation, and implementation of cleaner production opportunities (see Section 2.2.2 for further details).

The evaluation criteria for the comparative analysis of the currently available tools and methodologies were derived based on the author's extensive practical experience in the development and application of eco-efficiency and industrial ecology tools in close collaboration with industries (Van Beers 2000; Van Beers et al. 2007c). Table

2.2 outlines why the evaluation criteria are critical for the development of regional synergies in the case-study area.

As discussed earlier in this literature review, only a very limited number of industrial regions worldwide have applied synergy development tools. This indicates that currently available tools do not meet the specific research needs of the local organisations, including stakeholder engagement, flexibility in design and application, coverage of materials, energy, and water synergy opportunities, and required skills. This statement is supported by the comparative review provided in Table 2.1.

The comparative review shows that common elements of regional synergy development are only evident in the cleaner production framework. From Table 2.2 it is clear that any of the other evaluation criteria act as knock-out (elimination) factors for using the available tools (1 to 6) as a basis for the development of inorganic by-product, water, and energy synergies in the case-study area (Kwinana Industrial Area). Based on the comparative analysis presented in Table 2.3, the cleaner production framework appears to be the most suitable and, therefore, recommended approach to assist industries in heavy industrial areas with advancing regional synergy opportunities.

Table 2.2: Selection of Evaluation Criteria for Comparative Analysis

Criteria	Why Critical to Enhance Regional Synergy Development in Case-Study Area (Kwinana Industrial Area)?
Stakeholder engagement	Stakeholder engagement and consultation is a critical element in regional synergy development (e.g. industries, government, community). Tools and methodologies should accommodate stakeholder engagement processes, and not solely be focused on technical or economic aspects of the synergy development process.
Flexibility in design and application	Each industrial area is unique (in terms of industries, stakeholders, local issues, etc) and regional synergy development is subject to significant uncertainties. Tools and methodologies should cater for these features, and have flexibility in their design and application to allow for their application in different settings and local conditions (such as the Kwinana Industrial Area).
Proven industry track record	If the tools and methodologies do not have a proven track record in delivering sustainable solutions, these are likely going to be ineffective in the case-study area as well.

Criteria	Why Critical to Enhance Regional Synergy Development in Case-Study Area (Kwinana Industrial Area)?
Available in public domain	Tools and methodologies that are not available in the public domain have very limited potential to be applied elsewhere by other parties. It therefore limits their potential for widespread application.
Covers materials, energy, water	Key priority areas for advancing sustainable development through regional synergies (by increasing resource efficiencies and reducing wastes and emissions) in the case-study area (Kwinana) are inorganic by-products, water, and energy. Available tools and methodologies should be able to address all three priority areas.
Can be applied without high specialised skills by industry or academia	One should be able to apply the tools and methodologies with skills which normally should be available within the local industries or academia. If this is not the case, it will be difficult to apply these on a larger scale in different industrial estates.

Table 2.3: Comparative Analysis of Currently Available Tools and Methodologies

#	Tools and Methodologies	Covers all Common Elements of Synergy Development*	Could Include Stakeholder Engagement	Flexibility in Design and Application	Proven Industry Track Record	Available in Public Domain	Covers Materials, Energy, Water	Can be Applied Without Highly Specialised Skills by industries or academics	Comments
1	Web based "waste exchange" websites	No	No	Limited	Yes	Yes	Materials only	Yes	A variety of websites are available worldwide
2	Industrial Ecology Planning Tool (Nobel 1998)	No	Possibly **	Yes	Limited	Yes	Water only	No (GIS Software)	Includes assessment of transportation costs and scenario optimisation
3	MatchMaker! (Brown et al. 1997)	No	Possibly **	No	Limited	Yes	Materials only	Yes	Database framework without data
4	Industrial Materials Exchange (IME) tool (BCSD-GM 1997)	No	Possibly **	Yes	No details reported	No	Materials only	Yes	Appears to be the most widely cited tool for industrial ecology design
5	Facility Synergy Tool (FaST) (Industrial Economics 1998)	No	Possibly **	No	Limited	Yes	Yes	Yes	Limited choice of pre-determined facility profiles
6	Pinch analysis (Baas 1998)	No	Possibly **	Yes	Yes	Yes	Yes	No	Process integration tool
7	Customised methodologies based on proposed cleaner production framework	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Flexible framework which could be customised to meet specific industry needs

* Awareness & recruitment, data collection, analysis and synergy identification, implementation.

** These tools and methodologies do not include stakeholder engagement processes perse. However, these could be used as part of a stakeholder engagement process.

2.11 Conclusions from Literature Review

The concept of regional synergies is an emerging discipline of research and practice in the field of industrial ecology. The key components of regional resource synergies are collaboration and the synergistic possibilities offered by geographic proximity. The realisation of regional synergies in industrial areas with intensive minerals processing provides a significant avenue towards sustainable resource processing.

The literature review demonstrated that existing tools and methodologies for identifying regional synergies are lacking in practical applications, too narrowly focused, or not widely available. Given the absence of appropriate methodologies, the cleaner production framework seems to be a pragmatic and constructive approach to assist industries with the identification, evaluation, and implementation of regional synergy opportunities. The common elements of regional synergy development were addressed: (1) awareness and recruitment, (2) data collection, (3) analysis and synergy identification, and (4) implementation and continuation. These elements should be incorporated into any novel methodology to advance regional synergy development in a meaningful manner.

The Kwinana Industrial Area is an ideal case-study area for this research. A significant number of regional synergies are already in place, providing a range of sustainability benefits to the industries involved and the region as a whole. Furthermore, the successes and failures of regional synergy initiatives in the KIA provide important background information to the PhD research. Favourable features for further regional synergy development in the KIA include the Kwinana Industries Council, which provides a platform for industry collaboration, and the diversity of mostly non-competitive industries located in close proximity. There is a need for a detailed review of the existing synergies in Kwinana in order to gain a broader understanding of their business case, sustainability benefits, drivers, and barriers. This review will provide valuable information for the development of novel methodologies to further advance regional synergies in a systematic manner.

The strategy which will be used to address the gaps identified in the literature will be discussed in detail in Chapter 3 ‘Research Proposal’.

3 RESEARCH PROPOSAL

3.1 Introduction

A number of gaps in the current theory and practice have been identified in the literature review. These gaps are summarised in this chapter. The chapter then addresses the key sustainability challenges in the Kwinana Industrial Area to which regional resource synergies could make a positive contribution. These sustainability issues will be used to develop, demonstrate, and validate the methodologies (developed as part of this research) to fill the research gaps identified. The research aims and objectives arise from the state of knowledge in regional synergy development and the gaps identified in the theory and practices therein.

3.2 Summary of Gaps in Literature

In summary, the gaps identified in the literature review (Chapter 2) relate to:

§ The concept and theory of industrial ecology remains mostly untested or untried in real-world circumstances. The field of industrial ecology is still lacking in practical application (see Section 2.10.2).

§ The main focus of regional synergies research is on knowledge building, studying historical developments, and examining existing regional synergies. Although approaches to assist with regional synergy identification and development are emerging in various parts of the world (see Section 2.4.3), applied research on the development of new synergies in heavy industrial areas remains scarce overall (see Section 2.10.3).

§ Regional synergies worldwide have so far developed opportunistically in the absence of specific methods for synergy option generation. There is a need for structural development of synergy opportunities with particular relevance to heavy industrial areas.

§ There is lack of attention given to technological and engineering challenges specifically associated with regional synergy development. Traditional engineering tools focus on modelling and optimisation of material and energy flows within a process or a facility, but not between separate industries (see Section 2.4.4).

§ Despite the existence of some synergy identification tools, it was found that their application has been restricted to one or few industrial regions with a limited number of synergy opportunities implemented as a result (see Section 2.4.4).

To address these gaps, it is proposed to investigate the effectiveness of drawing common elements of regional synergy development into an overall framework generally used for the implementation of cleaner production (Figure 2.1), to assist industries in heavy industrial areas with advancing regional synergy opportunities. This framework will be the basis for the development of customised methodologies for progressing regional synergies in three key sustainability themes in the case-study area (the Kwinana Industrial Area): inorganic by-products, water, and energy.

The cleaner production framework (as shown in Figure 2.1) has been selected as the most appropriate and optimal framework for the research based on the following reasons:

§ The cleaner production concept has a proven track record in delivering business benefits and enhancing environmental performance of industry (CECP 2004; DEH 2001c; UNEP 1998).

§ A comprehensive and industry-focused approach is required to encourage and advance the process for regional synergy development. There is evidence that a committed approach to industrial synergies ultimately brings both economic and environmental benefits to the industries and communities involved.

- The process for identification and evaluation of potential synergies in an 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 cleaner production framework provides the basis for these activities to take place in a systematic manner.

- The cleaner production framework enables the ongoing assistance to the industries with the evaluation and development of promising opportunities which is of crucial importance to result in successfully implemented synergy projects.

3.3 Kwinana Industrial Area

Most regional synergies that currently exist within the KIA have developed opportunistically through industries pursuing perceived business opportunities, rather than through the systematic application of appropriate tools and methodologies. It appears that only the "low hanging fruit" opportunities have materialised in Kwinana. There is significant potential for the identification and implementation of more challenging synergy opportunities which can result in significant sustainability benefits. The outcome of the current work should therefore be a novel regional synergy development methodology, which is both highly practical and of use to both the scientific community and to industry.

Key sustainability challenges facing the KIA where regional resource synergies could make a contribution are:

- <u>Inorganic by-products:</u> Large volumes of inorganic by-products in the KIA are stockpiled from past operations (e.g. gypsum) and current operations (e.g. bauxite residue, kiln dusts, fly ash, iron making slag). The reuse of inorganic by-products has not yet materialised on a significant scale; a more collaborative and coordinated methodology may assist in realising the reuse of these by-products. The main focus of the research should be to find short-term reuses for high-volume inorganic by-products in local developments (Van Beers and Van Berkel 2005a).

- Water: Decreased rainfall has resulted in reduced rainfall runoff and less recharge to groundwater aquifers. This has impacted domestic and industrial water users by directly reducing available fresh water resources and indirectly by restricting potable (scheme) water available to industry. It is therefore urgent to investigate opportunities and implement reduced water consumption and effluent disposal from domestic and industrial users. Water consumption by industry and effluent discharges to the environment can be reduced through water utility synergies. The research focus should be on providing practical support to the Kwinana industries for the identification, evaluation, and implementation of feasible large volume water synergies (van Beers and van Berkel 2005b).

- Energy: Energy is also a key issue in the KIA. The discharge of waste heat is a significant source of energy loss in Kwinana operations using hot processes, utilities and/or process equipment. One way to further advance sustainable energy use is through the realisation of energy synergies. The primary aim of the research should be on the identification and evaluation of the economic, technical, and environmental feasibility of collaborative energy recovery opportunities in Kwinana. (Van Beers 2006).

It is therefore proposed to develop customised methodologies, based on the cleaner production framework, for each of these three sustainability challenges. This will ensure that each method is focused towards meeting the specific industry research needs and challenges in each priority area.

3.4 Research Aim and Objectives

As outlined in Section 1.2 ‘Project Aim’, the overarching aim of the PhD project is to research the effectiveness of drawing common elements of regional synergy development into an overall framework generally used for the implementation of cleaner production to assist industries in heavy industrial areas with advancing regional synergy opportunities.

The current status of the theory and practice of regional synergies, including the identification of gaps in the literature (specifically relating to heavy industries) was investigated in Chapter 2 ‘Literature Review’.

The research objectives that follow from the aim and the results of the literature review are as follows:

1. Assess existing regional synergies in the case-study area (Kwinana Industrial Area) in detail in order to extract background data and learnings for the development of approaches to identify and develop new synergy opportunities (Chapter 4).

2. Merge common elements of regional synergy development into an overall methodology framework, based on the cleaner production framework (Chapter 5).

3. Develop and trial customised methodologies, based on the cleaner production framework, to advance regional synergies in the case-study area with regard to inorganic by-products (Chapter 6), water (Chapter 7), and energy (Chapter 8).

4. Evaluate the results from the trial applications of the customised methodologies for advancing inorganic by-product, water, and energy synergies in the case-study area (Chapter 9).

5. Draw research conclusions based on the research findings in order to evaluate and validate the formulated research question, including recommendations for further research directions.

4 EXISTING REGIONAL SYNERGIES IN KWINANA

This chapter allows a baseline assessment of the existing synergies in the case-study area (the Kwinana Industrial Area), and the successes and failures to be established. Such work is an important precursor to the method development discussed in the following chapters.

This chapter is based on the journal article: Van Beers et al. (2007b).

4.1 Introduction

The existing synergies within the Kwinana Industrial Area are quite diverse, however generally fall in three principal categories (Bossilkov and Van Berkel 2004; Van Berkel 2003), i.e.:

§ Supply chain synergies: featuring local manufacturer and dedicated supplier of principal reagents for core process industries (e.g. production of ammonia and chlorine for industrial use).

§ By-product synergies: these involve the use of previously disposed by-product (as solid, liquid, or gas) from one facility by another facility to produce a valuable by-product (e.g. recovery and on-selling of carbon dioxide and hydrogen).

§ Utility synergies: these involve the shared use of utility infrastructure, and mainly evolve around water and energy (e.g. water recovery and cogeneration).

Even though the supply synergies provide the backbone for industrial integration in the KIA, these are not further addressed here ([2]). Such supply synergies are '*business*

[2] In some earlier publications, supply synergies were included in the assessment of the regional synergy achievements in Kwinana. As they do not meet the criterion of exchange between traditionally separate

as usual', where a business realises 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).

This chapter provides an overview of current regional synergies in the KIA, including a selection of detailed examples illustrating the specific sustainability benefits of regional synergy developments. The chapter then provides a comparative review of the drivers, barriers, and trigger events for regional synergies initiatives, followed by an assessment of common success factors of regional resource synergies.

4.2 Existing Regional Synergies

4.2.1 Overview

The inventory of existing synergies between 31 companies (21 core process industries and 10 service and infrastructure industries) showed that these are quite diverse in Kwinana. There are 47 synergies in place (Table 4.1), including 32 by-product synergies (Figure 4.1) and 15 utility synergies (Figure 4.2) (Van Beers et al. 2007b). The full list of the existing by-product and utility synergies are included in Appendices 1 and 2 of this thesis. 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 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.

industries, they have been eliminated here and this has resulted in lower total numbers of synergies (compared to numbers reported elsewhere by e.g. (Taylor 2002) and (Van Berkel 2003)).

Table 4.1: Total Number of Current By-Product and Utility Synergies in Kwinana

Synergy Type	# Projects	Flows Involved
By-product	32	22 Solid
		8 Liquid
		9 Gaseous
		40 Total
Utility and infrastructure	15	25 Water
		11 Energy
		36 Total
Total	**47**	

The diversity and maturity of existing synergies in Kwinana is quite remarkable, both in absolute terms, as well as in comparison to often-cited international examples (e.g. Kalundborg (Denmark), Forth Valley (UK), Rotterdam (Netherlands), etc) (Bossilkov et al. 2005). A number of factors are unique to Kwinana and these have without doubt contributed to regional synergy developments in the area. These include:

§ 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 centres in Eastern Australia and internationally;
§ A member-based industry organisation (Kwinana Industries Council) which addresses a broad range of issues common to the industries in the area;
§ The vicinity to Perth as a major metropolitan centre;
§ The gradual urban encroachment around the industrial area; and
§ The growing recognition for the natural resource value of the Cockburn sound on which shore the KIA is located.

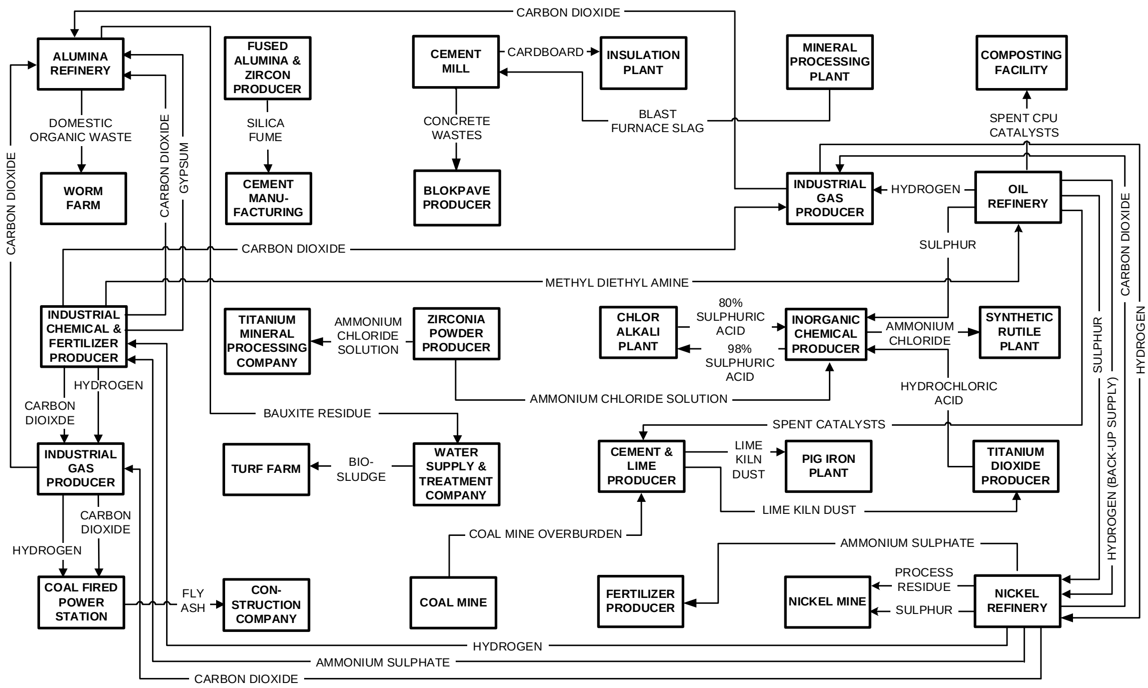

Figure 4.1: Existing By-Product Synergies in Kwinana (Van Beers et al. 2007b)

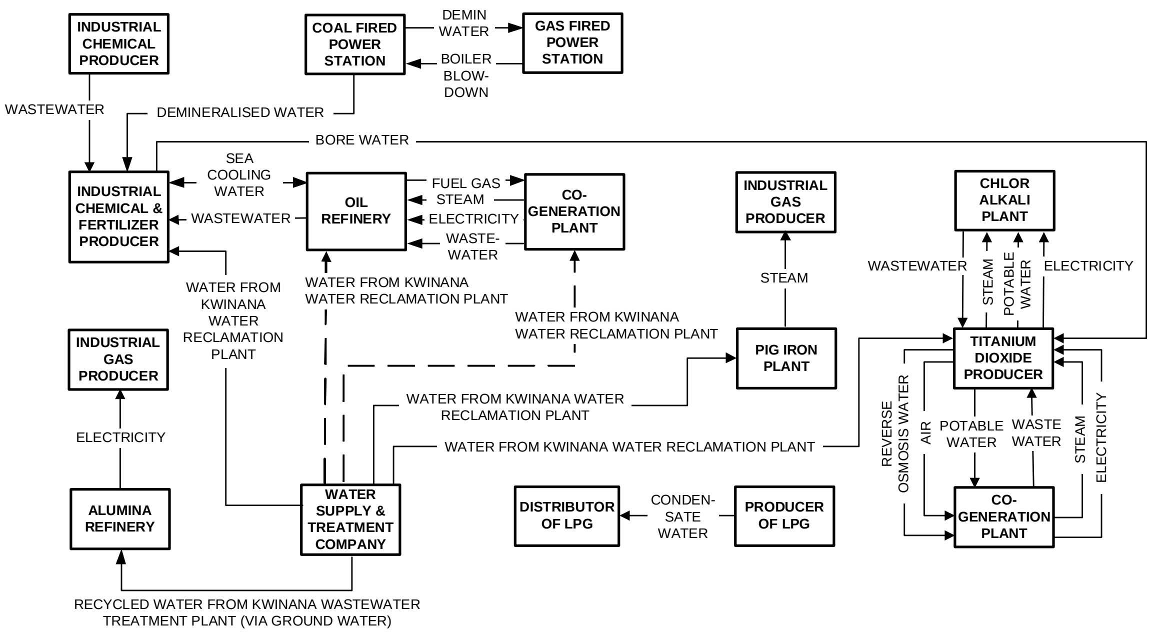

Figure 4.2: Existing Utility Synergies in Kwinana (Van Beers et al. 2007b)

4.2.2 Examples of By-product Synergies

Pigment plant supplying hydrochloric acid to chemical manufacturer to produce ammonium chloride

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 kilometres from the Kwinana refinery. The cost of the ammonium chloride to Tiwest is significantly less than that previously imported (DEH 2001a).

Chemical plant supplying food grade carbon dioxide to utility gas provider

Since 1990 Air Liquide purifies and compresses process CO_2 received from CSBP (from its ammonia plant) and other industrial facilities in the KIA to a standard suitable for use as food grade CO_2 for soft–drinks and beer. CO_2 is also used for other applications such as in dry ice and water treatment, often at much lower price. This initiative reduces the emissions of carbon dioxide to atmosphere, while also avoiding energy use that would otherwise be required to produce CO_2 from air.

Chemical plant supplying gypsum for residue area amelioration at alumina refinery

CSBP produced gypsum (calcium sulphate, $CaSO_4$) 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 long since ceased, 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.

Chemical plant supplying carbon dioxide for residue neutralisation at alumina refinery

Alcoa's Kwinana alumina refinery is about to start using process carbon dioxide (CO_2) to reduce the alkalinity of its bauxite residue, thus reducing environmental risks and significant ongoing management related to bauxite residue storage areas while also leaving options open for additional processing of the residue into other useful products at a future stage. The residue carbonation process was identified after many years of research into reuse potential and modification of the bauxite residue by mixing it with other industrial by-products or residues. The Kwinana refinery will tap into a consistent and concentrated source of process-CO_2 from a nearby ammonia plant, resulting in greenhouse gas benefit equal to 70,000 tonnes CO_2-eq per year and generation of a more benign waste that provides alternative reuse opportunities (Alcoa 2005).

4.2.3 Examples of Utility Synergies

Reuse of recycled effluent from Kwinana Waste Water Treatment Plant (WTTP) at the alumina refinery

Treated wastewater from Kwinana wastewater treatment plant is infiltrated into groundwater upstream from Alcoa groundwater extraction bores. 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 Alcoa at an estimated rate of 1.1 GL per annum.

Cogeneration plant at oil refinery

The Kwinana Cogeneration Plant (116 MW capacity) is located on land of the BP Kwinana oil refinery, and produces all process steam for the refinery, in addition to generating electricity for BP as well as the grid. The cogeneration plant is fired with natural gas supplemented with excess refinery gas. The cogeneration plant built in 1996 took the place of the BP steam boilers which were in need of replacement at the time. Total benefit has been estimated as a reduction of about 170,000 tonnes of carbon dioxide emissions per annum. 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 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.

Cogeneration plant at titanium dioxide pigment plant

Built in 1999, the second cogeneration facility (40 MW), owned by Verve Energy, was constructed to provide superheated steam for 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.

Chemical plant supplying water to pigment plant

Tiwest established its pigment plant in the KIA after the groundwater allocation for the area had already been licensed to the existing industries. Their process requires a significant amount of potable water, which for a drought-affected Western Australia, is not the most sustainable option. In addition to vigorous water efficiency achievements, Tiwest now supplements potable water intake with 1.4 GL per year of CSBP groundwater supplies, allocated by the State's authorities.

Artificial wetland treatment at chemical plant

In 2004 CSBP chemicals and fertiliser operations built an innovative nutrient stripping wetland to further reduce its nitrogen discharges to the adjacent Cockburn Sound. The "pilot" wetland was constructed on land leased from BP refinery. The wetland is planted with sedges and incorporates a number of biological processes that will reduce the level of nitrogen in CSBP's effluent stream. If the pilot is a success over a two-year trial period three more cells will be constructed. Some of the BP's effluent is also released into the wetland and it is found to provide additional benefits by supplementing the carbon loading provided by plant organic matter.

4.2.4 Emerging Regional Synergies

The dynamic nature of industry development in Kwinana means that some of the 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. There is no formal collaborative process for managing this on a regional scale. It is questionable if such a formal process would be beneficial (it is outside the scope of this PhD research). This is a "natural" process affecting any business, and is part of normal business practice to adjust to new circumstances. On the other hand, new opportunities will emerge with the establishment of new industries in the area. In this case, there is an opportunity for undertaking a synergy scoping study to investigate to the synergy opportunities emerging from the new development.

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

§ The world's first commercial 800,000 tonnes/yr direct reduction iron making plant (HIsmelt). This technology provides a 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 CO_2, 40% reduction of NO_x, and 90% reduction of

SO_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).

§ 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 some Kwinana industries (e.g. pig iron plant, industrial chemical producer, pigment plant, oil refinery, and the 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 reduce chemical use in cooling towers and other process applications, which in turn 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 industrial effluents into the deep ocean outfall (about 4 kilometres off the coast) through the pipeline belonging to the water utility company, thereby eliminating process water discharges to the sensitive coastal area (Water Corporation 2003).

4.3 Sustainability Benefits of Regional Synergies

For a synergy to be successful, all involved parties must benefit in one way or another. In fact, it is unlikely that a synergy would be implemented unless all involved parties at least perceive some business benefit (direct or indirect). The full range of benefits from regional synergies is often not recognised by the industries. To illustrate this, Table 4.2 presents a summary of the commercial, environmental, and community benefits for some existing synergies in Kwinana.

Table 4.2: Illustrative Benefits of Regional Synergies

Synergy	Commercial Benefits	Environmental and Community Benefits
CSBP gypsum reuse at Alcoa residue area	§ Reduced costs to manage gypsum stockpile (long-term) § Lower cost gypsum source for alumina refinery	§ Reduction of stockpiled gypsum onsite at chemical plant § Increased soil stability and plant growth at Alcoa residue area
Air Liquide utilising by-product CO_2 from Kwinana industries	§ Costs savings for industrial gas company to produce food grade CO_2 from otherwise emitted CO_2 emissions	§ Proportion of CO_2 emissions from industries are no longer emitted to the atmosphere § Avoidance of energy use that would otherwise be required to produce CO_2 from air
2 Cogeneration facilities (BP, Tiwest)	§ Increased energy efficiency § Reliable source of electricity and superheated steam § Sales of electricity and steam from cogeneration plant	§ Reduced greenhouse gas emissions § Increased energy efficiency § Employment
Kwinana Water Reclamation Plant (KWRP)*	§ Water security for industry users § Availability of high-grade water for industry	§ Potable water conservation § Redirection of discharges of treated industrial effluent from coastal zone into deep ocean § Water quality improvement in sensitive coastal zone

* A more comprehensive assessment of the triple bottom line impacts of these regional synergies is available from (Kurup et al. 2005).

As illustrated in Table 4.2, 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 the synergies presented here. In addition, all of these synergies generate 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 improved reputation. The critical factor in initiating a regional synergy is for all the involved parties to fully appreciate the range of benefits, both direct and indirect, which will result from its implementation (Corder et al. 2006).

It is acknowledged that regional synergy development will come at a cost to the companies involved, and that synergies may have negative social and environmental impacts if applied inappropriately without consideration of these impacts. A business case assessment (evaluation of costs versus economic returns) is common industry practice before making an investment decision. The research presented in this thesis seeks to identify and develop synergies that make a contribution to sustainable development on a regional scale through increasing resource efficiencies and reducing wastes and emissions. It is outside the scope of this thesis to undertake a detailed triple bottom line assessment of regional synergy opportunities, in particular the social aspects. This topic is addressed by a separate PhD study which is currently being finalised and therefore not yet in the public domain.

4.4 Comparative Review of Drivers, Barriers and Trigger Events

Valuable lessons can be learned from regional synergy experiences in Kwinana. Table 4.3 includes a selection of the main drivers, barriers, and triggers for these synergy developments. Although not all drivers, barriers, and trigger events listed in the table below can be discussed in detail, some specific examples from Kwinana are provided below to illustrate each of the main categories referred to in the table.

Table 4.3: Drivers, Barriers, and Triggers for Regional Synergies (Van Beers et al. 2007b)

<table>
<tr><th>Category</th><th>Drivers</th><th>Barriers</th><th>Triggers</th></tr>
<tr><td>Economics</td><td>§ Increased revenue through lower operational costs
§ Reduced risks and liability</td><td>§ Relatively low price for utility resources
§ Relatively low costs for waste disposal</td><td>§ Secure availability and access to vital process resources</td></tr>
<tr><td>Information availability</td><td>§ Local industry organisation
§ Staff mobility</td><td>§ Confidentiality and commercial issues</td><td>§ Local and regional studies</td></tr>
<tr><td rowspan="2">Corporate citizenship and business strategy</td><td>§ Corporate sustainability focus</td><td>§ Core business focus</td><td rowspan="2">§ Industry champion</td></tr>
<tr><td colspan="2">§ Community engagement and perception</td></tr>
<tr><td>Region-specific issues</td><td>§ New company entering industrial area
§ Geographic isolation</td><td>§ Distance between companies</td><td>§ Major new project developments</td></tr>
<tr><td>Regulation</td><td>§ Existing environmental regulations (e.g. air and water quality requirements and reporting)</td><td>§ Existing environmental regulations (intensive approval procedure for by-product reuse)
§ Existing water and energy utility regulations</td><td>§ New pollutant targeted regulations (e.g. carbon tax and mandatory energy audits)</td></tr>
</table>

Category	Drivers	Barriers	Triggers
Technical issues	§ Research and technology developments § Technical obsolescence of existing process equipment	§ Availability of (reliable) recovery technologies	§ Major brownfield development

4.4.1 Economics

§ Operational costs and revenue as a synergy driver: Most synergies 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 meets all three. Dilute hydrochloric acid is generated from scrubbing the gas stream from the chlorination step in the titanium dioxide pigment plant. The acid was previously neutralised 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 hydrochloric acid from the first scrubber has become a valuable by-product. It is sold on to Coogee Chemicals to produce ammonium chloride which it then transports (via road) to Tiwest's synthetic rutile plant some 75 kilometres from the Kwinana plant. The cost of the ammonium chloride to the synthetic rutile plant is significantly less than that which was previously imported, while wastewater costs have been reduced and revenues increased at the pigment plant (DEH 2001a).

§ Resource scarcity 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. The Kwinana Water Reclamation Plant was built to accommodate the establishment of HIsmelt which could not get access to another suitable source of process water.

4.4.2 Information Availability

- Staff mobility as a synergy driver: Mobility of staff between neighbouring operations in Kwinana has contributed to a greater awareness of industrial operations, and their associated process inputs and outputs, which has contributed significantly to identifying synergy opportunities.

- Local and regional studies as a synergy trigger: While a number of synergies were already happening in Kwinana, it took an external study to review and document regional resource flows and synergy opportunities to trigger broader industry interest. 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 the industry integration in the area over the 1990s, and suggested many more exchanges would in principle be possible. The discussions in the project steering group for this study led to the direct realisation of some synergies, such as for example the reuse of waste gypsum from CSBP by the Alcoa bauxite residue operation.

4.4.3 Corporate Citizenship and Business Strategy

- Community engagement and corporate citizenship focus as a synergy driver: The KIA is increasingly subjected to urban encroachment and the resulting higher community expectations, with regard to environmental and safety performance, and overall amenity. The KIA 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, BP and Kwinana Cogeneration Plant to purchase the higher cost water from KWRP. Moreover the CSBP chemical and fertiliser 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. Some of BP's effluent is also released into the wetland, which provides additional benefits by supplementing the carbon loading provided by the plant organic matter.

§ Core business focus as a synergy barrier: The focus of site personnel is to devote their efforts to core business activities. This can result in potentially missed synergy opportunities unless there is an overwhelming commercial benefit. This is recognised by various site personnel, who see one of the principal aims of the regional synergies research being the identification and progression of synergy opportunities which are unrelated to their core business.

4.4.4 Region-Specific Issues

§ Major capital projects as a synergy driver and trigger: This can include new operations or significant capacity expansion projects in existing operations. In Kwinana, two new industrial facilities have been built and commissioned in 2004 (Kwinana Water Reclamation Plant and 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 Perth Metro.

§ Distance between companies as a synergy barrier: Although the KIA is relatively compact, the distances still pose a challenge with regard to the recovery and reuse of by-products, water, and energy. This is particularly the case when a low value resource from a Kwinana company is used outside the boundaries of the KIA, for example the use of inorganic by-products for building and construction. The challenge is to keep the required transportation distances to a minimum. It does not make good business sense to consider a reuse where the low-value resources needs to be transported over large distances (>50 or 100 kilometres).

4.4.5 Regulation

§ Environmental regulations as a synergy barrier: Some Kwinana companies are experiencing obstacles in getting governmental approvals for the use of alternative fuels and raw materials. Although some by-product synergies appear techno-economically feasible and have positive economic, environmental, and social impacts (e.g. alternative fuels in cement kilns, and use of bauxite residue for soil conditioning), their practical implementation have 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.

§ New pollutant targeted regulations as a synergy trigger: Business drivers for energy conservation are changing rapidly, through for example the introduction of mandatory energy opportunity assessments (and their public disclosure) for large users (> 0.5 PJ/yr) in 2007, climate change policies and potentially carbon taxes. It is anticipated that these developments will result in improved energy efficiency and enhanced energy recovery at Kwinana operations, possibly through energy utility synergies.

4.4.6 Technical Issues

§ Technical obsolescence of existing process equipment as a synergy driver: The Kwinana Cogeneration Plant, located on land belonging to the BP oil refinery, produces all process steam for the refinery, and generates electricity for BP as well as the grid. The cogeneration plant built in 1996, took the place of the BP steam boilers that 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.

§ Major brownfield expansion as a synergy trigger: In Kwinana, a major new industrial development that further enhances regional synergies in the region is the world's first commercial direct reduction iron making plant (HIsmelt). 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.

4.5 Common Factors of Successful Synergies

As previously stated, for a synergy to be successful, all involved parties must benefit in one way or another. In fact, it is unlikely that a synergy would be implemented unless all involved parties at least perceive some business benefit (direct or indirect) (Corder et al. 2006). For all synergy examples presented in this thesis there are both tangible operating benefits as well as less tangible benefits, such as reputation, environment or community (see Section 4.3). When developing synergy opportunities for the KIA, it is most important to maintain a focus on these key success factors.

A recent review of international case-studies on synergy enabling mechanisms came to a similar conclusion that the realisation of successful synergies is dependent on three main aspects: proven technology, convincing business case, and license to operate (CECP 2007).

4.5.1 Technology

Proven and viable process technology and equipment is 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. Over the past decade water treatment through reverse osmosis has become a viable technology to enable water utility synergies, as illustrated by the Kwinana Water Reclamation Plant (KWRP). It is acknowledged that the KWRP has energy impacts (energy requirements to operate plant). However, it is believed that the water savings from the KWRP outweigh its energy requirements. It is interesting to note that the energy impacts were not addressed in the public environmental review undertake prior to the establishment of KWRP (Water Corporation 2003).

Technology can pose a challenge to the development of regional synergies. This is the case in regard to the recovery and use of inorganic by-products in Kwinana. An illustrative example is the Alcoa alumina refinery which has been separating the sand and mud fractions of its residue. Alcoa is now assessing the suitability of the mud fraction as soil improver and as feedstock for value recovery (e.g. lime, alumina, titanium and iron). Alcoa is also assessing the potential of further separation of the sand fractions to produce sand fractions that would be suitable for construction applications.

4.5.2 Business Case

The benefits of regional synergies go beyond ‘business-as-usual’ and financial benefits. The broader sustainability benefits of synergies are not often well understood. Traditionally, company decision making for new projects is based on return-on-investment rates. A more comprehensive and inclusive approach is required to demonstrate and account for the economic, social, and environmental benefits of the life cycle of a new synergy opportunity.

Once a potential technical synergy ‘match’ has been identified (that is a realistic technical opportunity for a by-product being generated by one operation which can be used at a neighbouring operation), both the by-product generating and receiving operations need to identify the business case in developing this synergy. There must be compelling evidence that financial and other business benefits outweigh the project costs and risks. As with any new project or change in current practices, a significant effort in both time and money is required from both parties. It is typically easier to continue with current practices. For instance, the generator continues to dispose of the by-product in the usual manner, often to landfill, and the potential consuming operation continues purchasing the material that the by-product would otherwise replace as systems and contractual arrangements are already in place.

This status quo can be changed when there is an appreciable financial or other business benefit for both parties in developing the synergy. This is particularly true if both the cost-benefit analysis for both the producer and consumer of the by-product satisfies their respective financial criteria. Under these conditions, the decision makers in the respective companies have a sound quantitative analysis to assist them in the final evaluation on the synergy project. Where the decision to implement a synergy becomes more difficult is when the business case does not meet the financial criteria but would produce other significant but less tangible benefits, such as reputation, environment or community. These cannot be incorporated into the standard cost-benefit analysis or in many cases cannot be quantified at all. As part of an ARC research project on synergy enabling mechanisms, a novel approach on Triple Bottom Line Accounting is being developed and trialled in Kwinana and Gladstone to help build a more comprehensive business and societal case for material and energy exchanges, leading to improved regional sustainability (Kurup et al. 2005).

4.5.3 License to Operate

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 undesirable impact on their lifestyle through waste or emissions disposal practices this could affect the company's 'license 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. This can drive the development of regional synergies. This is illustrated to various extents with some of the synergy examples discussed in this thesis (Sections 4.2 and 4.3): reduced use of scheme water by industries by sourcing high quality industrial water (treated wastewater) from the Kwinana Water Reclamation Plant, reduced use of landfill by utilising by-products as an alternative raw materials, and reduced storage of gypsum through reuse as a soil amendment.

4.5.4 Industrial Networking

An industrial network operating in a region can significantly advance the development of opportunities for industries to work together for the common good of the industrial area. Kwinana has this network: the Kwinana Industries Council (KIC). KIC is an incorporated business association and advances a broad range of common interests of the companies in the KIA. It pursues its goals through a number of committees set up to provide input on issues of common interest to the member companies. Committee members are volunteers with appropriate experience and authority from the member companies (KIC 2005). These committees provide an avenue for discussion of issues of common interest and a mechanism for progressing collaborative activities.

The industry network establishes lines of communication between companies in the region that may not have any direct or obvious business reason to communicate. By establishing this process of communication and continuing it on a regular basis (typically KIC committees meet either monthly or bi-monthly), there is a much greater understanding and appreciation of the important and common issues across operations in the region. This engenders a greater level of cooperation and trust between the operations and consequently helps smooth the way for the development of new synergy opportunities and other joint initiatives. The importance of building relationships between representatives of the companies in the region should not be underestimated and is an essential component of the development of synergies.

4.5.5 Business Benefits

The key to the development of any regional synergy is that each of the participating parties derives a benefit. As illustrated in earlier in this chapter, the types of benefits can vary greatly and often go well beyond the conventional ‘business case’ (direct economic) benefits. Security of water and energy supply, increased energy efficiency, lower operational costs for energy use, and reduced stockpiling costs are key benefits from the Kwinana synergies. The examples 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 practical benefits of the existing synergies serve as case studies of the expected benefits of potential synergies on a theme (water, energy or inorganic by-products) basis. The experiences in Kwinana demonstrate that the industries perceive an overarching benefit to the individual companies involved and region as a whole from the implemented synergies (also taking into account the required capital and operational costs). The critical factor in initiating a regional synergy is for all the involved parties to appreciate fully the range of benefits (and associated costs), both direct and indirect, that will result from its implementation.

4.6 Conclusions from Existing Synergies in Kwinana

The initial phase of this research has confirmed the close collaboration and integration that already exists within the KIA. This has initially developed in response to perceived business opportunities and environmental and resource efficiency considerations. The existing synergies in Kwinana greatly exceed 'business-as-usual', and are more diverse and significant than those reported for other heavy industrial areas (Bossilkov et al. 2005). This positions Kwinana among the international leading edge examples of regional synergy development. The benefits of existing synergies in Kwinana often go well beyond the conventional business case benefits. Resource security, increased efficiency, lower operational costs, reduced landfill disposal, and employment are some of the key benefits from regional synergies which have been presented in this chapter. There is widespread enthusiasm and commitment from the local industries to achieve greater regional synergies, and thereby make further contributions to sustainable development in the area.

Overall, the assessment of the existing synergies in the KIA, as presented in this chapter, has generated the following lessons for the method development discussed in the following chapters:

- It is clear that there is no "one-size-fits-all" approach to develop regional synergies; each synergy is unique in terms of its drivers, barriers, business case, and sustainability benefits. Therefore, significant flexibility will need to be incorporated in the methodologies if these are to be successful. The Cleaner Production Framework (Figure 2.1) provides a broad and overarching structure for the development of synergy development methodologies customised to the specific research needs of the industries and uniqueness of each synergy opportunity.

- The drivers, barriers, and triggers for regional synergy development in Kwinana appear to fall into six broad categories: economics, information availability, organisational and social issues, region-specific issues, regulations, and technical issues. A wide range of drivers and barriers exist which are influenced by diverse set of stakeholders (e.g. companies, regulators, community). The complete set of drivers, barriers, and trigger events, rather than one specific aspect, determines the business and sustainability case of a regional synergy opportunity, and hence are key to the development and implementation of new synergy projects. These factors need to be incorporated appropriately in methodology development for this PhD research.

- Many diverse regional synergy opportunities still appear to exist in the KIA, mostly in three broad areas: water, energy, and inorganic by-product reuse. Therefore, the customised methodologies will need to focus on three priority areas (see also section 2.8.4).

- A review of international case-studies (CECP 2007) illustrated the importance of proven technology, a convincing business case, and license to operate to the development of a successful synergy project. These three key success factors have to be addressed in the methodology development and its application in the KIA.

- 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 recognised by most industries that the business case for synergies does not solely depend on the financial benefits, but is also affected by other sustainability aspects such as risk management, continued access to vital resources, environmental legislation, and community relations. These additional business benefits must be communicated as part of the trial application of the customised methodologies in Kwinana.

5 METHODOLOGY FRAMEWORK

5.1 Introduction

Figure 5.1 presents the methodology framework to identify, develop and evaluate new regional synergy opportunities in the case study area (the Kwinana Industrial Area). This approach was compiled by merging common elements of synergy project development (awareness and recruitment, data collection, analysis / identification, implementation and continuation, as outlined in Section 2.4.4) into an overall framework generally used for the implementation of cleaner production within companies (Figure 2.1) (Van Berkel 2002). Each phase within the methodology framework is discussed separately in the following sections.

It is acknowledged that the cleaner production framework presented in Figure 5.1 is based on the generic continuous improvement PDCA Deming cycle (Plan-Do-Check-Act). UNEP and UNIDO have used this Kaizen process as a basis for the development of the Cleaner Production approach. Over the years, the UNEP/UNIDO's approach to cleaner production, based on the generic PDCA umbrella concept of Deming, has been referred to the 'Cleaner Production Framework'.

The methodology framework shown in Figure 5.1 was the basis for the development of customised methodologies for advancing regional synergies in the following three themes: inorganic by-products (Chapter 6), water (Chapter 7), and energy (Chapter 8).

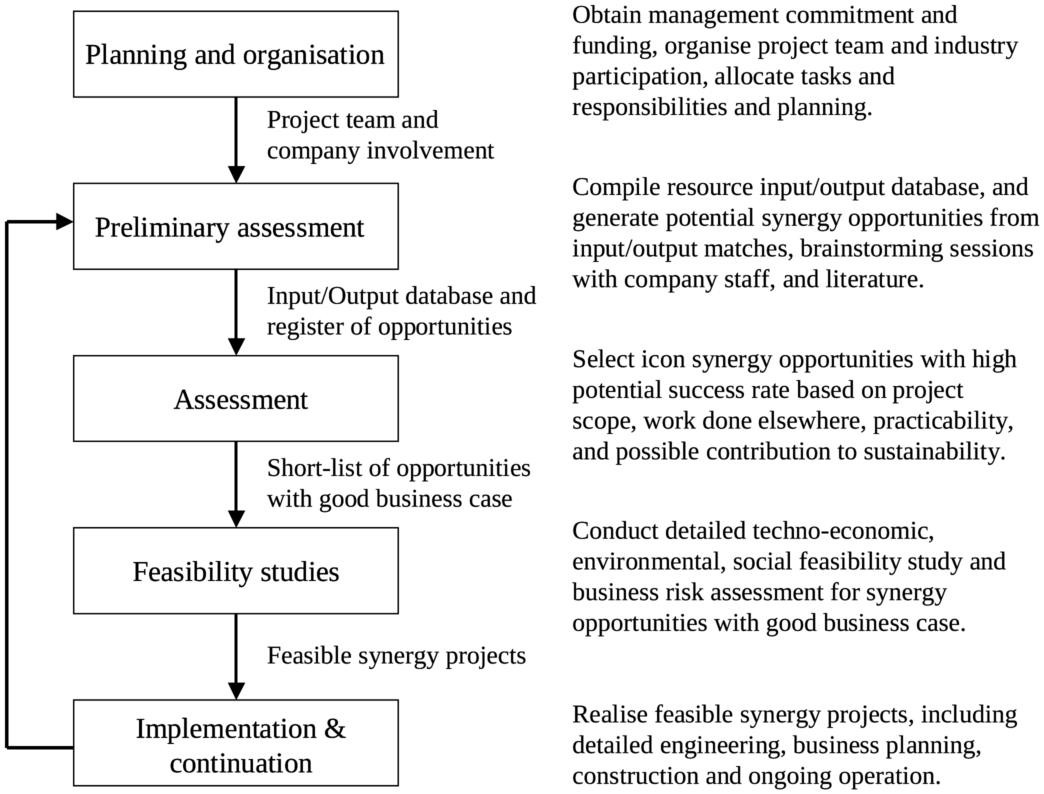

Figure 5.1: Cleaner Production Framework to Advance Synergy Opportunities (Van Beers et al. 2005a)

The justification of the selection of the cleaner production framework as the basis for the development of customised methodologies for advancing inorganic by-product, water, and energy synergies is discussed in section 2.10.4.

5.2 Planning and Organisation

Recruitment of companies into the research focused initially on the member companies of the Kwinana Industries Council but later extended to include other significant businesses in the region. The companies were visited by the researcher to introduce the research, commence the data collection and set up confidentiality agreements (if necessary) to enable release of company data on their materials, energy and water consumption and discharges. These company visits achieved high participation levels which was crucial to the success of the research.

The planning and organisation phase also consisted of organising initial workshops with the industries. The overall objective of these workshops was to discuss the status quo the generation of inorganic by-products, energy consumption, water consumption and to scope the research work required to advance regional synergy development.

5.3 Preliminary Assessment

5.3.1 Data Collection

Standardised data collection sheets were developed to gather the necessary information in the most efficient and effective way from the participating companies. The data collection sheets were prepared for each company based upon the findings of the introductory visit. A database was created to store, manage and manipulate the company data provided. The database was a valuable tool and a platform for storing and processing company information and served as a search engine into the identification of regional synergies. Although the database was developed specifically for the Kwinana case study, it is also applicable to other industrial regions elsewhere in the world. Illustrative lay-outs and forms of the database are included in Appendix 3.

5.3.2 Identification of Synergy Opportunities

The search for potential new synergies was undertaken in tandem with the baseline data collection, as discussed above. Potential synergies were identified through four activities: the resource flow database; review of earlier reports on synergy opportunities in Kwinana (in particular the KIA economic impact studies (SKM 2002); (SKM 2007); on-site discussions with company representatives; and focused opportunity identification workshops with the Kwinana industries.

5.4 Assessment

The assessment phase covered in-depth evaluations of the selected focus areas in order to develop a comprehensive list of available synergy opportunities. This included detailed qualification and quantification of the inorganic by-product, water, and energy input and output flows within the case-study area.

The aim of this phase was to identify promising synergy opportunities which have potential to result in significant sustainability and business benefits for the industries involved and the industrial region as a whole (so-called ‘icon synergies’).

5.4.1 Prioritisation of Synergy Opportunities

Not all identified potential synergies were feasible or provided significant benefits to the companies or the region. Screening exercises were conducted to eliminate those synergies that could readily be identified as unfeasible or without significant benefits.

The prioritisation of the synergy opportunities was based on the following criteria:

1. <u>Scope:</u> the synergy should fit the aims and objectives of the research project;
2. <u>Complementary:</u> the option is not yet being pursued by the companies themselves or other parties;
3. <u>Achievability and benefits:</u> the synergy should have the potential to be practically achievable and provide benefits to the companies involved;
4. <u>Sustainability:</u> the opportunity should have the potential to make a significant contribution to sustainable development in the KIA, mainly through increasing resource efficiencies and reducing wastes and emissions.

In the context of the thesis, the prioritisation of synergy opportunities is believed to contribute to sustainable resource processing if the synergy leads to increasing resource efficiencies and reduced wastes and emissions without having significant negative economic, environmental, or social impacts. It is not claimed that the prioritisation process leads to the identification of synergies which result in ‘sustainable resource processing’. The prioritisation processes result in a preliminary ranking of a set higher and lower priority opportunities for consideration by the industries. It is beyond the scope of this thesis to quantify the economic, environmental, and social aspects (positive and negative) for each of the synergy opportunities identified. Relevant aspects are, were, or will be qualified in the detailed feasibility studies of selected opportunities. Tailored and pragmatic prioritisation processes were developed for each of the three customised methodologies (inorganic by-products (section 6.2.4), water (section 7.2.4), and energy (sections 8.2.5 and 8.2.8). The prioritisation processes for the three methodologies are discussed in Chapter 9.

The prioritisation exercises resulted in short-lists of those synergy opportunities with a potential for success and significant benefits to the involved companies and the region as a whole. It was envisaged that some synergy opportunities require further follow-up to determine whether or not these are worth further investigation. Some synergy opportunities were already subjected to investigation by other parties, in which case they were not considered as part of this research. However, it was of interest to track the progress of these developments as well.

5.5 Feasibility Studies

In order to streamline the limited research resources and to be able to advance the work in a meaningful manner, the research focused on selected tasks to further develop regional synergies in the KIA. It was crucial that the Kwinana industries select the synergy opportunities for feasibility studies, as the companies involved must be willing to work together with the researcher(s) to progress the synergy.

The type and level of research assistance to the selected synergies depended on the specific research needs of the involved industries. There was no one-size-fits-all approach for the development of regional synergies. In summary, the research contribution to the development of selected synergies comprised 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.

If it became clear that it was not worthwhile to pursue a selected potential synergy any further, then other more promising synergy opportunities were investigated.

5.6 Implementation and Continuation

A critical factor for the research was the actual implementation of new synergy opportunities by the industries in Kwinana. The responsibility and outreach of the research could only go as far as developing initial proxy plans for implementation. Eventually it remained the responsibility of the individual companies to decide whether and how to pursue feasible synergy opportunities.

Various mechanisms are in place to ensure the continuation of the regional synergies research in the KIA. Firstly, the awareness, desire, and commitment of the industries and the KIC to the successful implementation of further synergies; thereby improving their sustainability and business performance. Secondly, strategic engagement between the research team and the industries (mainly through the KIC) takes place on a regular basis to address emerging issues, opportunities, and challenges. Thirdly, the application of the customised methodologies (discussed in the following chapters) is targeted towards meeting specific industry research needs. As a result, the regional synergies research in Kwinana is continued with a further two years (until June 2010) with support of the industries (through the KIC) and the Centre for Sustainable Resource Processing. The ongoing research is building upon the methodologies and outcomes presented in this thesis.

5.7 Conclusions from Methodology Framework

This chapter showed that the common elements of synergy development (awareness & recruitment, data collection, analysis and synergy identification, implementation and continuation) can be merged into a framework generally used for the implementation of cleaner production in industries. The framework was the basis for the development and application of customised methodologies for advancing regional resource synergies in the three key priority areas for the KIA: inorganic by-products (Chapter 6), water (Chapter 7), and energy (Chapter 8). The evaluation of the customised methodologies (based on the framework presented in this chapter) is discussed in Chapter 9.

The information and communications flows of the proposed cleaner production framework will initially target the Kwinana industries and the KIC. Where needed, the customised methodologies for inorganic by-products, water and energy will seek broader access of communication and engagement with relevant stakeholders. The KIC will provide a platform to identify and develop these “external” linkages and communications. It is acknowledged that opportunities may exist for establishing broader communication forums (e.g. web-base, inter-regional or multi-sectoral) to broaden the opportunities for regional synergy development. On the other hand, it is understood that cleaner production (intra-first) and regional synergies within the KIA should be fully explored first, before considering synergies and communications with industries outside the Kwinana area. This is mainly because of the associated capital and operational costs to transport by-products, water, and energy (mainly “low value” resources) over larger distances. The focus of this PhD research is on the establishment of regional synergies within the Kwinana region.

6 METHODOLOGY TO ADVANCE INORGANIC BY-PRODUCT SYNERGIES

This chapter is based on the journal article: Van Beers et al. (2009).

6.1 Introduction

Despite the fact that Kwinana already has a large number of synergies by world standards (Bossilkov et al. 2005), large volumes of inorganic by-products are still being disposed of within the Kwinana Industrial Area. This applies to bauxite residue, fly ash, cement and lime kiln dusts, gypsum, iron making slags and other processing residues. These are valuable materials that could serve as alternative resources for building and construction projects, agricultural applications, minerals and metals production and other applications. Their utilisation as valuable by-products will significantly reduce liabilities associated with current management and storage practices.

The opportunity exists to replace virgin materials with inorganic by-products from industrial operations in Kwinana, either directly or after some processing to improve properties. This has not yet materialised on a large scale, due to the fragmented approach adopted by the Kwinana industries in the past and a range of barriers associated with their reuse (e.g. governmental approval process and absence of reuse guidelines).

This chapter discusses the development and application of a customised methodology to drive the implementation of inorganic by-product synergies in Kwinana on a significant scale. The chapter ends with concluding remarks on the lessons learnt to date, as well as how the implementation of successful inorganic by-product synergies can be enhanced in the future.

6.2 Developed Methodology

The customised methodology to advance the reuse of inorganic by-products in the Kwinana case-study is illustrated in Figure 6.1. The interrelation between the cleaner production framework and the customised methodology is detailed in the left column of the figure below. Each step in the methodology is described in the next sections.

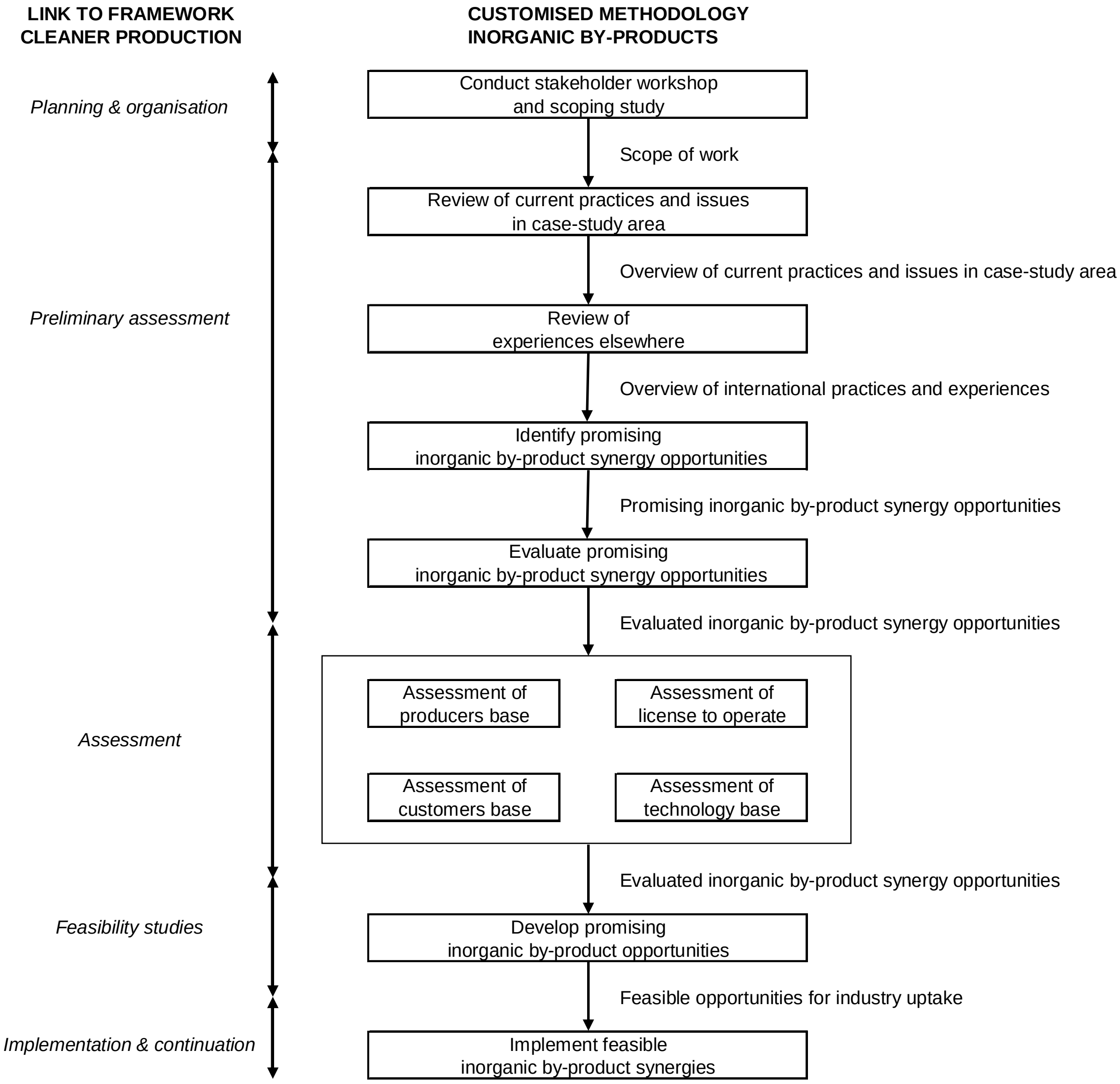

Figure 6.1: Customised Methodology to Advance Inorganic By-Product Synergies

6.2.1 Stakeholder Workshop and Scoping Study

An initial workshop with Kwinana industries and other stakeholders (e.g. local government) was organised to review past and ongoing initiatives on the reuse of key inorganic by-product streams in Kwinana, and discuss potential ways forward to realise the reuse potential for these industrial inorganic by-products.

Following up on the initial industry workshop, a detailed scoping study was conducted to investigate the potential achievability and business and sustainability benefits for further advancing the recovery and reuse of inorganic by-products within the KIA. Discussions with individual industries were held to review current practices, specific research needs, and important issues to be considered for the development of a customised methodology for inorganic by-product reuse.

The stakeholder workshop and subsequent scoping study with the Kwinana industries delivered the customised methodology to enhance the recovery and reuse of inorganic by-products (Figure 6.1).

6.2.2 Review of Current Practices and Experiences

Unsuccessful initiatives of individual industries to find reuses for their inorganic by-products have led to large stockpiles of these materials in Kwinana (fly ash, bauxite residue, gypsum, slag, kiln dusts). Inorganic by-product synergies have not yet been implemented on a large scale. However, there are a number of small scale reuse projects already in place. The (un)successful initiatives provide valuable lessons for the collaborative efforts to further progress the reuse of these materials. A review of these initiatives has been carried out, including a detailed assessment of the drivers, barriers, and triggers for inorganic by-product synergies in Kwinana.

6.2.3 Review of Practices and Experiences Elsewhere

From the initial stakeholder workshop and scoping study, it was clear that regulations in Western Australia do not cater for the promotion of the alternative materials at present. The reuse of inorganic by-products appears more diverse and common practice internationally. Therefore, a review of national and international experiences and practices was completed in order to provide perspectives and learnings for the KIA (Bossilkov and Lund 2008b). The relevant components from this report are discussed later in this thesis (Section 6.3.4).

6.2.4 Identification of Promising Opportunities

Discussion with the Kwinana industries that produce the inorganic by-products led to a selection of promising synergy opportunities which could be further developed. These promising opportunities were assessed in detail as part of the subsequent stages of the customised methodology. The selection criteria included potential volumes of reusable materials, potential business and sustainability case of the reuse opportunities, and work already done by the individual industries. It was anticipated that with the selected options the most significant progress and impact could be made to establish short-term solutions to utilise large volume inorganic by-products available within the KIA.

6.2.5 Evaluation of Promising Opportunities

Earlier in this thesis (Section 4.3), it was found that all existing regional synergies in Kwinana have resulted in tangible operating benefits as well as less tangible benefits, such as reputation, environment, and community benefits. As part of the customised methodology for inorganic by-products synergies, an assessment was made of the sustainability benefits of the promising opportunities selected for this work (see Section 6.3.6). This information is valuable in the communications with the external stakeholders involved (e.g. government and community) about the sustainability benefits of inorganic by-product reuse. In addition, the drivers and barriers for promising inorganic by-product synergies have been evaluated in order to identify means to enhance (in case of drivers) or eliminate (in case of barriers) these.

6.2.6 Assessment of Producers, Customers, License to Operate and Technology

The assessment of the producers base, customers base, license to operate, and technology base is at the heart of the developed methodology. Each of these components is summarised below.

§ <u>Producers base:</u> gain an understanding of the quantities and qualities of inorganic by-products available in the KIA. Individual industries have already collected most data as part of their environmental management strategy and past efforts to find reuses for their by-products. As part of the methodology, data gaps have been filled where required.

§ <u>Customers base:</u> assess the potential customers and markets for promising synergy opportunities in three main categories with largest potential for reuse: infrastructure and construction, minerals and metals production, and other (e.g. agriculture and soil treatment).

§ <u>License to operate:</u> At a minimum all government approvals should be in place, but preferably also endorsement from affected communities, key non-governmental organisations and/or an opportunity to create or improve skills, jobs and/or livelihoods. The regulatory process of approval for by-product reuse is at present a difficult and demanding process. The reuse of an inorganic by-product can easily be thrown into disrepute through any sudden opposition from the community or other groups. Without specific regulatory guidelines, there remains no solid ground for a company to be confident of regulatory and community support.

§ <u>Technology base:</u> evaluate the technologies which can improve the materials' characteristics through beneficiation and processing of different by-products. Through combination of specific fractions of different inorganic by-products it would to a certain extent be possible to produce a beneficiated by-product that better meets customer expectations. Examples are the blending of by-product gypsum into a soil conditioner, currently being pursued by Manna Enterprises working with CSBP chemical and fertiliser plant, and the production of a superior quality road base material from fly ash and Alcoa's bauxite residue sand.

6.2.7 Development and Implementation of Feasible Opportunities

From the work it was strongly evident that the Kwinana industries are experiencing obstacles in getting governmental approvals for reuse of their inorganic by-products.

The focus for the development and implementation phases is on the initiation and establishment of reuse guidelines for selected synergy applications (ongoing research). It is anticipated that implementation of inorganic by-product synergies will follow from development of the reuse guidelines.

6.3 Results from Application of Methodology

This section provides an overview of the results from the collaborative Kwinana methodology to advance the reuse of inorganic by-products on a significant scale.

6.3.1 Stakeholder Workshop and Scoping Study

The stakeholder workshop and detailed scoping study resulted in the methodology (Figure 6.1) that enabled a transparent, trust worthy, and accountable process to achieve the full potential of inorganic by-product synergies (Van Beers and Van Berkel 2005a). The industry and government representatives present at the workshop expressed an interest and willingness to work together in a more collaborative manner on inorganic by-product reuse.

From an industry perspective, it was clear that there were a number of important issues that need to be taken into account such as confidentiality, commercial issues, stakeholder engagement (i.e. community and government), and legislative issues. The research interests varied significantly per company and reuse opportunity.

It was recognised that a collaborative methodology would be preferable, both in terms of developing an effective framework for assessment and (government and community) approval, as well as in terms of having an opportunity to improve the materials' characteristics through beneficiation and processing of different by-products. Through combination of specific fractions of different inorganic by-products it would to a certain extent be possible to produce beneficiated by-products that better meet customer expectations.

From the scoping study and industry work, it became clear that the anticipated benefits of a collaborative research methodology are:

- § Enhancing credibility by working together (industry, research, government, community);
- § Addressing the barriers collectively;
- § Learning from other experiences;
- § Establishing critical mass to gain overall acceptance of recovery and reuse projects;
- § Aligning recovery and reuse projects with strategic directions of local and State government and the community.

6.3.2 Synergy Initiatives of Inorganic By-Products

6.3.2.1 Successful Synergy Initiatives

Although inorganic by-product synergies have not yet been implemented on a large scale in the KIA, a number of small scale reuse projects have succeeded (see Figure 4.1). Some illustrative examples are listed below:

- § Reuse of gypsum from chemical plant for soil amendment: CSBP produced gypsum, calcium sulphate, as a by-product of the manufacture of phosphoric acid. Even though this practice has ended long ago, there remains a stockpile of some 1.3 million tonnes. As part of an extensive review into reuse options, it was determined that the gypsum could be utilised by Alcoa's alumina refinery to assist in plant growth and soil stability in its residue areas. Alcoa now takes this material on an ongoing basis, approximately 10,000 tonnes each year. In addition, CSBP is working with Manna Enterprises to blend the gypsum with lime kiln dust for use as soil conditioner. This is a long-term project and may enable the gypsum stockpile to be remediated in about two decades (Spears 2005).

- § Reuse of lime kiln dust from cement plant for desulphurisation: Cockburn Cement supplies lime kiln dust from its quick lime operation to HIsmelt (direct smelting pig iron trial plant) for their desulphurisation process. There is potential for the cement producer to take the gypsum (produced from the desulphurisation process) in return and use it in the cement making process as raw material. The latter exchange will depend on the suitability of the gypsum properties for the cement process; this will be known once the HIsmelt plant is fully commercially operational. The cement producer also supplies lime kiln dust to a titanium dioxide pigment plant (Tiwest).

§ Reuse of silica fume from fused alumina and zirconia producer: Australian Fused Materials (AFM) produces a high purity silica fume as a by-product during the manufacture of fused zirconia. AFM supplies the silica fume to building and construction sector (concrete producer) as a mineral admixture in high strength and durable concrete.

6.3.2.2 Unsuccessful and Unrealised Synergy Initiatives

Synergy opportunities have to some extent been evaluated and implemented for each of the main inorganic by-product streams. Individual industries have had numerous attempts to implement large scale reuses of their inorganic by-products, but without success so far (these are summarised in Table 6.1).

Table 6.1: Attempts from Individual Companies to Develop Inorganic By-Product Synergies (Van Beers and Van Berkel 2005a).

Company	Inorganic By-Product	Unrealised Reuse Applications – Attempts from Individual Companies
Alumina refinery	Red sand	Untreated: fill and road sub-base High silica fraction: concrete fine aggregate, coatings industry, glass, High iron fraction: iron ore feed, cement Mid fraction: fill, cement, drain filters
	Red mud (Alkaloam™)	Soil and manure additive, sources of fines (fill, asphalt, concrete, bricks, blocks, fines), feed for value recovery
	Red lime	Neutralisation (e.g. flue gases, acid soils, subsoils, mine tailings), cement geopolymers, feed for value recovery (Al, CaO)
Cement plant	Lime kiln dust	Recycling back into lime manufacturing process (under investigation)
	Cement kiln dust	Unknown

Company	Inorganic By-Product	Unrealised Reuse Applications – Attempts from Individual Companies
Chemical plant	Phospho-gypsum	Plasterboard, bricks
Pig iron plant	Iron making slag	Soil treatment, acid water neutralization, cement substitute, alumina production, general or road construction material (e.g. filler, aggregate)
Coal-fired power station	Fly ash	Agriculture, turf farm, cement
	Bottom ash	Roadbase material, inert fill for water pipelines

Three illustrative unsuccessful initiatives undertaken over the past decade are listed below:

§ <u>Reuse of red mud for agricultural applications:</u> Alcoa's red mud (Alkaloam™) has the ability to increase phosphorous retention in soils, making it a very suitable material for soil conditioning. Alcoa and the Department of Agriculture and Food, Western Australia (DAFWA) have performed extensive research on the use of Alkaloam™ as a soil amendment (Summers et al. 2002; Summers et al. 2004; Summers et al. 2001; Cooling and Jamieson 2004). Extensive laboratory, field and catchment-scale trials have repeatedly shown the ability to reduce the leaching of nutrients to sensitive regional waterways, while at the same time increasing pasture productivity (Summers et al. 2001). This research has been ongoing for more than 10 years, and has resulted in generally positive feedback from farmers. Alcoa have found that the regulatory process of approval for by-product reuse is at present a difficult and demanding process. Nevertheless, the use of a company's by-product can easily be thrown into disrepute through any sudden opposition from individual community members or other groups. The delicacy of the operating environment was exemplified in an article in 2002 in the Sydney Morning Herald. In true journalistic style, the largely discredited article took the story of one farmer, who had applied Alkaloam™ in excess of Alcoa's recommendations, and claimed (among other sensationalising comments) that the soil had become 'radioactive'. In actuality, Darling Scarp soils and rocks where Alkaloam™ originates, have naturally higher levels of radiation than the sandy soils of the Coastal Plain in WA. Understandably, Alcoa sought and received indemnity from any environmental damage resulting from the misuse or application outside the guidelines. Without specific regulatory guidelines, there remains no solid ground for a company such as Alcoa to be confident of regulatory support, despite years of scientific evidence demonstrating only positive benefits of the use of products such as Alkaloam^{TM} (Harris 2007).

- Reuse of gypsum for plasterboard and cement manufacturing: CSBP chemical and fertiliser plant conducted work on the reuse of phospho-gypsum in plasterboard. It turned out that their gypsum tends to slightly discolour the plasterboard. The consumer perception is that this discolouring compromises the quality of the plasterboard which is not the case. There is an opportunity to blend in the phospho-gypsum with natural gypsum which will significantly reduce the discolouration. In addition, CSBP worked with Cockburn Cement to investigate the use of the phospho-gypsum as feedstock for cement manufacturing. The cement company would have to upgrade its feeding system because of the relatively small particle size of the gypsum (150 microns), therefore the business case was not justified.

- Reuse of fly ash for soil amendment: The University of Western Australia conducted research on the reuse of fly ash from the coal-fired power station in Kwinana as a soil conditioner on turf farms. This reuse application was initially implemented successfully but has halted later because certain batches of fly ash contained some wild grass seeds, which caused issues with the turf farmers. This could be resolved with a modified fly ash handling process (e.g. removing top layer of fly ash), but the quantities involved with this reuse do not justify the modification.

6.3.3 Drivers, Barriers, Triggers

Valuable lessons can be learned from the (un)successful initiatives to develop and implement inorganic by-product synergies in Kwinana. Table 6.2 includes a selection of the main drivers, barriers, and triggers for these initiatives. Although not details can be discussed in this chapter, an elaboration and illustrative successful and unsuccessful examples are provided in the following subsections to illustrate each of the main categories referred to in the table.

Table 6.2: Drivers, Barriers and Trigger Events for Inorganic By-Product Synergies

Category	Topic	Driver	Barrier	Trigger Events
Successful initiatives*	Regulation		X	Good corporate citizen Low cost raw material Reduced disposal costs
	Economics	X	X	
	Community		X	
	Technology			
	Transportation	X	X	
	Confidential & commercial issues		X	
	Risk & liabilities	X	X	
	Industry focus & priorities	X		
	Region-specific issues	X		
Unsuccessful & unrealised initiatives**	Regulation		X	Lack of community and government support Low return on investment Required technology modifications
	Economics	X	X	
	Community		X	
	Technology		X	
	Transportation	X	X	
	Confidential & commercial issues		X	
	Risk & liabilities	X	X	
	Industry focus & priorities	X	X	
	Region-specific issues		X	

* As depicted in Figure 4.1.
** As summarised in Table 6.1.

6.3.3.1 Regulation

Kwinana industries are experiencing obstacles in obtaining governmental approvals for reuse of inorganic by-products and the use of alternative fuels. Although some by-product synergies appear technically and economically feasible and have a positive sustainability impact, practical implementation has often been halted by uncertainties in the legislative framework, in particular with regard to the final responsibility for approved reuse options, and community concern. A company's investment in inorganic by-product reuse therefore has a lack of security, especially where community concerns (whether justified or not) can effectively end the initiative. As a result, by-products continue to build up in storage facilities, and this practice is likely to increase in the future with new companies in the start-up phase and further operations being planned in Kwinana (Harris 2007).

6.3.3.2 Economics

As with any new project or change in current practices, a significant effort in both time and money is required from both parties. It is typically easier to continue with current practices. For instance, the generator continues to dispose of the by-product in the usual manner, often to landfill, and the potential consuming operation continues purchasing the material that the by-product would otherwise replace as systems and contractual arrangements are already in place. This status quo can be changed when the cost-benefit analysis for both the producer and consumer of the by-product satisfies their respective financial criteria. Where the decision becomes more difficult is when the business case does not meet the financial criteria but would produce other significant but less tangible benefits, such as reputation, environment or community. These cannot be incorporated into the standard cost-benefit analysis or in many cases cannot be quantified at all (Corder et al. 2006). A more comprehensive and inclusive approach is required to account for the economic, social and ecological benefits over the entire life cycle of a synergy opportunity. As outlined in sections 1.2 and 1.3, the aim of this research is to develop and apply methodologies (based on the cleaner production framework) that assist with the identification and development of regional synergy opportunities. Thereby, the focus is on enhancing the sustainability of the industries and the region by reducing wastes and emissions and increasing resource efficiencies. It is outside the scope of this thesis to investigate or develop tools or methodologies for the triple-bottom-line accounting of regional synergy opportunities. This is a topic in itself which is addressed elsewhere (Kurup et al. 2005).

6.3.3.3 Community

Individual synergies can result in substantial benefits for the community and region such as employment, reduced negative impact on the local environment through reduced dust and transport emissions, and increasing the regional security of water and energy through reduced industrial use (see Table 4.2). As shown so clearly with Alcoa's initiative to reuse Alkaloam^{TM} for agricultural applications (see Section 6.3.2), the reuse can easily be thrown into disrepute through any sudden opposition from the community or other groups. Also, CSBP's efforts to reuse their gypsum as a source material for plasterboard were deferred pending better market conditions. The potential for future community opposition and public concern, which is often not based on sound science, results in a strong disincentive for industries to pursue reuse of their inorganic by-products.

6.3.3.4 Technology

Proven and viable process technology and equipment is 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 specifications. Without a suitable technology available to convert or transport the by-product, a synergy project is not viable. Lack of suitable technology can pose a challenge to the development of regional synergies. In Kwinana, an illustrative example is the Alcoa alumina refinery which has been separating the sand and mud fractions of its residue. Alcoa is now assessing the suitability of the mud fraction as soil improver and as feedstock for value recovery (e.g. lime, alumina, titanium and iron). It is also assessing the potential of further separation of the sand fractions to produce sands that would be suitable for construction applications. Another example where technology poses a barrier is the reuse of CSBP's phospho-gypsum for cement manufacturing by Cockburn Cement because of the relatively small particle size of the material (150 microns).

6.3.3.5 Transportation

With regard to transportation issues and costs, a distinction must be made between synergies where the inorganic by-product is reused by another (Kwinana) industry or where the by-product is reused in more dispersed applications (such as road construction or agricultural products). Because the KIA is a relatively compact site (about 8 by 4 kilometres), transportation costs will have a limited impact on the economic viability of a synergy opportunity between two Kwinana industries. However, transportation becomes an important issue when evaluating the business case of reuse applications involving larger distances and dispersed uses.

Transportation costs can also be a driver for regional synergy development. For example, transportation typically accounts for up to one third of the production costs of cement and concrete aggregate in Western Australia (Van Beers et al. 2006). This is because “virgin” raw materials have to be transported from far north or south of the Perth Metropolitan Area. Also, natural gypsum is mined about 200 kilometres from Perth. Transporting the natural gypsum to production facilities and/or consumer markets in urban areas account for the main costs for the production of natural gypsum. These high transportation costs would be reduced significantly if the quarried materials are substituted with inorganic by-products that are available locally in the KIA.

6.3.3.6 Confidential and Commercial Issues

There may be competing reuse applications for the inorganic by-products in Kwinana – i.e. the reuse of a particular by-product for an application may automatically preclude the reuse of other by-products. For example, the demand for alternative raw materials in cement manufacturing can vary sharply with small variation in the composition of the other raw materials. If fly ash is reused in clinker production, there is likely no need to source bauxite residue (Davis 2005). In addition, inorganic by-products will have to compete with the traditional “virgin” raw materials. In a lot of cases, conventional raw materials can be made available at low costs. Inorganic by-products, as an alternative to these materials, will have to compete with these low costs.

Confidentiality issues between Kwinana industries do not pose a significant barrier to the development of synergies. There is limited competition between the diverse blend of key processing and manufacturing industries in the KIA. In addition, the KIC provides a platform for industry collaboration. However, confidentiality issues play an important role when industries with a new revolutionary technology enter the

KIA such as the HIsmelt pig iron plant. This plant produces large volumes of slag with valuable properties for reuse. The characteristics of this by-product will only be known and made available once the plant becomes fully commercial.

6.3.3.7 Risks and Liabilities

The utilisation of large volumes of inorganic by-products would significantly reduce liabilities and the future management requirements associated with current storage practices. From this perspective, risks and liabilities are a driver for regional synergy development. On the other hand, a company's investment in a by-product reuse has a lack of security, especially where community concerns can blow out of proportion and effectively end the reuse. In these cases, risks pose a barrier to the development of inorganic by-product synergies.

The sustainability benefits that can emerge from regional synergies come at a significant effort. Synergy development involves a number of complex processes with many stakeholders involved. The management of this process is therefore a crucial factor for success (van Berkel 2006a). In pursuing regional synergies, all stakeholders should realise the challenges and risks involved when entering into an inorganic by-product synergy, for example (modified from (Lowe 1997):

- Companies using each other by-products as inputs face the risk of losing a critical supply or market if a plant is closed down or changes its product mix;
- Proprietary information could be available to competitors;
- Uneven quality of the by-product materials could cause damage to equipment or quality of products;
- Possible innovations in regulations to enable the development of synergies may not be allowed by regulatory agencies.

Customised facilitating structures (ways to increase information sharing and collaboration) and operational and contractual arrangements (ways for companies to share the risks and benefits) would assist with reducing the risks and liabilities involved in regional synergy development.

6.3.3.8 Industry Focus and Priorities

The emphasis of site personnel is to devote their day-to-day efforts to core business activities resulting in potential missed synergy opportunities unless there is an overwhelming commercial benefit. This is recognised by the KIC and its member companies which see one of the main aims of the regional synergies research is to identify and progress synergy opportunities, which are not directly related to core business. An illustrative example is the HIsmelt plant with its first commercial scale application of direct smelting technology. As expected, the current main focus of HIsmelt staff is on the getting the operations fully commercial. However, it is recognised that finding reuses for the slag is an important sustainability issue, and that increasing amounts of slag will be produced as the plant's pig iron production increases.

6.3.3.9 Region-Specific Issues

The dynamic nature of industrial development in the KIA means that some of current synergies might cease to exist in the future as businesses improve their own processes or decide to relocate. Vice versa, new opportunities will emerge with the establishment of new industries in the area, as has been so vividly illustrated with the establishment of the HIsmelt plant. Furthermore, various new power generation projects are being planned for Western Australia, and these projects will likely go ahead over the next few years. These developments will influence the decision making on the future use of the coal-fired Kwinana power station. The increasing age of the Kwinana station results in increasing carbon content of the fly ash which may influence the uptake of certain reuse applications for the fly ash (e.g. cement making). In addition, the composition and properties of fly ash vary significantly by region, depending on the technological features of the power station and the type and quality of coal that is combusted. As a result, the fly ash produced by the Kwinana power station is therefore different from other coal-fired power stations.

6.3.4 Practices and Experiences Elsewhere

As outlined earlier in this chapter, transportation of by-products can be a barrier to potential synergy development. One of the major potential applications for the utilisation of the inorganic residues generated within KIA is the reuse in infrastructure, residential and commercial developments. These need to be within a reasonable distance to favour the preference of alternative versus virgin materials.

The national and international review for the utilisation of inorganic by-products (Bossilkov and Lund 2008b) is focused on their application to engineering projects. Agricultural or other applications are not a focus of this review, due to their relatively large spread.

6.3.4.1 National

Australian utilisation experiences are somewhat limited to a small number of inorganic by-products. Generally accepted materials are iron and steel slags, as well as fly ash, which could be contributed to the existence of industry associations with primary objectives to conduct research and technology transfer on behalf of their members and to assist in developing market opportunities for these materials.

Iron and Steel Slag is accepted and used as a cement replacement with combined utilisation rate for 2003 – 69% (Gregory and Jones 2005). Slag has been utilised in national projects such as Sydney Harbour Tunnel, the third runway at Sydney airport, sea wall of the Sydney Opera House forecourt, the construction of the concrete walls, floors and beams in many of Sydney 2000 Olympic venues and many others.

Fly ash is another readily reused material in Australia. For the year 2006/07, approximately 13.5 Mt (million tonnes) of coal combustion products (CCP's) were produced within Australia and New Zealand. Of the CCP's produced, some 6.2 Mt (about 46%) can be said to have been effectively utilised. 13% or 1.74 Mt was used in high value added applications such as cementitious applications or concrete manufacture, while 0.7 Mt (about 6%) was used in non-cementitious applications. In all, 3.7 Mt (about 27%) was used in projects offering some beneficial use (i.e. mine site remediation, local haul roads etc.). From 1990 to 2006, utilisation rates have increased from 8% to 46% (ADAA 2007).

Flue Gas Desulphurisation Gypsum - In 1998 the Clean Gypsum project was jointly entered into by Pasminco Hobart Smelter (PHS) and Australian Cement Holdings (ACH) to investigate the production and use of market quality chemical gypsum. ACH at Railton produces around 1.2 million tonnes of cement annually and uses approximately 50,000 tonnes of mineral gypsum to achieve this. With all the relevant issues addressed and resolved to the satisfaction of both ACH and PHS a three year supply contract was entered into. Since 1999 gypsum from PHS has been transported to the ACH Railton plant and mixed on a 1:3 ratio with natural mineral gypsum sources (DEWR 2003).

Australian regulations do not cater for the promotion of the alternative materials at present. Although many by-products such as fly ash, iron and steel slag and recycled road materials have been reused in some applications, methods for evaluating the engineering and environmental suitability of these materials have not been formally developed. Some state agencies (e.g. NSW Road Transport Authority and VicRoads in Victoria) have adopted specifications for facilitating the potential for using the recycled materials. The absence of definitive methods of evaluation and specific criteria for determining the suitability of using these have limited the reuse of many other inorganic residues. The relatively widespread utilisation of fly ash and iron and steel slag in Australia can be linked to the existence of industry associations related to these materials.

6.3.4.2 International

The international experiences presented in Table 6.3 are much more varied. This is contributed mainly to the existence and continuous development of regulatory reuse standards and protocols in USA, various European countries and the European Union as a whole, promoting and facilitating the reuse of the mentioned inorganic by-products in roadworks and generally in the construction industry.

Table 6.3: International Examples of Inorganic By-Products Reuses (Bossilkov and Lund 2008b)

Inorganic By-Product	Country	Rate of Reuse	Typical Applications	Reference
Sand (foundry)	USA	32-45%	Construction fill and concrete	(Anon. 2007); (Guney et al. 2006)
	Finland	n/a	Insulation structures	(Mroueh and Wahlstrom 2002); (FHWA 2000)
Chemical gypsum	USA (FGD)	93%	Not specified	(ACAA 2004)
	EU (FGD)	67-100%	Not specified	(ECOBA 2004); (ECOBA 2005); (FHWA 2000)
Iron making slag	USA	90%	Aggregate in concrete	(FHWA 2000)
	NZ	n/a	Sub-base aggregate, sealing chip, stabilising additive	(LTNZ 2006)
	EU	40-100%	Road constructions, aggregate in concrete, cement production, aggregate in unbound layers	(FHWA 2000)
Fly and bottom ash	USA	27-31%	Cement production; structural fill (fly ash), asphalt aggregate; granular base (bottom ash)	(FHWA 2000)
	NZ	n/a	Filler, stabilising additive	(LTNZ 2006)
	EU	Fly ash 40-100% Bottom ash 70-100%	Not specified	(ECOBA 2004); (ECOBA 2005); (Mroueh and Wahlstrom 2002); (FHWA 2000)
Construction and demolition debris	EU	10-100%	Aggregates in concrete, embankments and fill, concrete and masonry granulates	(FHWA 2000); (Vázquez and et al 2004); (QPA n.d.)
Recycled concrete aggregate	NZ	n/a	Pavement base or sub-base aggregate	(LTNZ 2006)
	EU	81%	Not specified	(FHWA 2000)
Recycled asphalt pavement	NZ	n/a	Recycled asphalt, sub-base aggregate	(LTNZ 2006)
	USA	80%	Aggregate in hot and cold mix asphalt; asphalt cement binder	(FHWA 2000)
	EU	55-100%	Recycled to pavement, wearing courses and bases, new asphalt	(FHWA 2000)
Cement kiln dust	USA	65%	Not specified	(FHWA 2000)

The EU has a long history of promoting alternative materials. Extensive collaborative research initiatives have been initiated to promote the reuse of alternative materials as a contribution to sustainable development. The two main initiatives are:

- The EU Alternative Materials Framework (CORDIS (n.d.); TRKC 2003) carried out to remove the uncertainties associated with using alternative materials; and
- The EU "thematic network", established to promote the use of recycled materials as aggregates in the construction industry.

As one outcome of the above initiatives, the EU introduced the new European Standards for aggregates in 2004. A significant aspect is that these standards are for "aggregates from natural, recycled and manufactured materials", focusing on fitness for purpose and not discriminating between different resources (AggRegain n.d.).

In the USA, the Environmental Protection Agency (USEPA) has developed an action plan (USEPA 2005) for the beneficial use of secondary materials, specifically focusing on coal combusting products, foundry sand and construction and demolition debris. Many states have the so-called 'Industrial Waste Reuse Programs' (USEPA 2002) that vary in approaches for the approval of inorganic by-product reuses. Nevertheless all of these programs are aimed at the promotion of recycling the emphasis on the importance of waste reduction and more efficient use of resources.

In New Zealand, Transit New Zealand have recently promoted the use of industrial by-products and recycled materials by including specifications for the use of smelter slag, crushed concrete and waste glass in the current specification for premium base course aggregates (TNZ 2006). In addition Transit New Zealand has developed 'Best Practice Guidelines for the Use of Alternative Materials and Processes in Road Construction' (TNZ 2006), featuring alternative materials such as asphalt millings, recycled concrete, steel slag, scrap tyres and glass cullet.

6.3.5 Identification of Promising Opportunities

Based on discussions with the Kwinana industries, a selection was made of promising synergy opportunities which could be further developed as part of the customised collaborative methodology (Figure 6.2). This selection were subjected to detailed assessment and created transparency to the involved stakeholders, including the industries, government, and community.

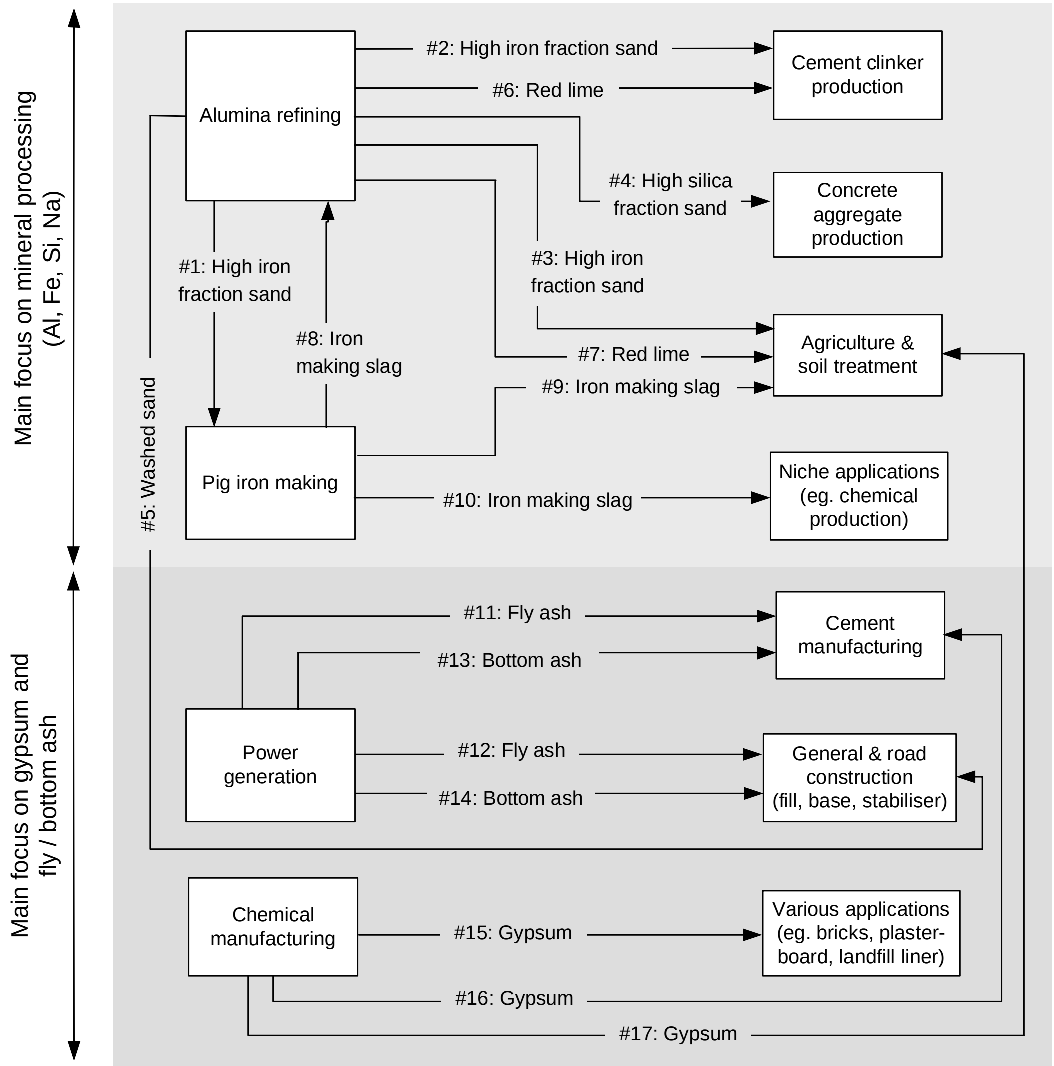

Figure 6.2: Promising Synergy Opportunities for Inorganic By-Products (Van Beers et al. 2006)

6.3.6 Evaluation of Promising Opportunities

6.3.6.1 Sustainability Benefits

Table 6.4 presents a summary of the economic, environmental, and community benefits for the promising synergies presented in Figure 6.2. The table shows that the types of benefits can vary greatly and often go well beyond the conventional business case benefits. Resource security and efficiency, reduced landfill costs, and lower operational costs are key benefits from potential inorganic by-product synergies in Kwinana. In addition, all these synergies will have environmental and community benefits. These 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.

Table 6.4: Sustainability Benefits of Promising Inorganic By-Product Opportunities

Synergy #	Potential Economic Benefits *				Potential Environmental and Community Benefits *				
	Reduced Landfill / Stockpile Costs	Lower Cost Raw Material	Increased Resource Security	Increased Resource Efficiency	Less "Wastes" to Landfill	Reduced Impact of Stockpiled Inorganic By-Products	Reduced Impact of Extracting "Virgin" Resources	Employment	Improved Living Conditions
1	ü	P	ü	ü	ü	ü	ü		
2	ü	P	ü	ü	ü	ü	ü		
3	ü	P	ü	ü	ü	ü		P	
4	ü	P	ü	ü	ü	ü	ü		
5	ü	P	ü	ü	ü	ü	ü		
6	ü	P	ü	ü	ü	ü	ü		
7	ü	P	ü	ü	ü	ü		P	
8	ü	P	ü	ü	ü	ü	ü		
9	ü	P	ü	ü	ü	ü		P	
10	ü	P	ü	ü	ü	ü	P	P	
11	ü	P		ü	ü	ü	ü		
12	ü	P		ü	ü	ü	ü		
13	ü	P		ü	ü	ü	ü		
14	ü	P		ü	ü	ü	ü		

Synergy #	Potential Economic Benefits *				Potential Environmental and Community Benefits *				
	Reduced Landfill / Stockpile Costs	Lower Cost Raw Material	Increased Resource Security	Increased Resource Efficiency	Less "Wastes" to Landfill	Reduced Impact of Stockpiled Inorganic By-Products	Reduced Impact of Extracting "Virgin" Resources	Employment	Improved Living Conditions
15	ü	P		ü	ü	ü	P	P	
16	ü	P		ü	ü	ü		ü	
17	ü	P		ü	ü	ü	ü		

* P = possibly

1. Use of high iron fraction bauxite sand for pig iron production
2. Use of high iron fraction bauxite sand for cement clinker production
3. Use of high iron fraction bauxite sand for agriculture and soil treatment
4. Use of high silica fraction bauxite sand for concrete aggregate production
5. Use of washed sand for general and road construction
6. Use of red lime for cement clinker production
7. Use of red lime for agriculture and soil treatment
8. Use of iron making slag for alumina refining
9. Use of iron making slag for agriculture and soil treatment
10. Use of iron making slag for niche applications (e.g. chemical production)
11. Use of fly ash for cement manufacturing
12. Use of fly ash for general and road construction
13. Use of bottom ash for cement manufacturing
14. Use of bottom ash for general and road construction
15. Use of gypsum for various applications (e.g. bricks, plasterboard, landfill liner)
16. Use of gypsum for agriculture and soil treatment
17. Use of gypsum for cement manufacturing

6.3.6.2 Drivers and Barriers

Table 6.5 presents an evaluation of the promising reuses of inorganic by-products in the KIA. From the table it is clear that all synergies have been (and some still are) driven to various extents by individual Kwinana industries. Seven out of the seventeen reuses are now being evaluated through the collaborative Kwinana methodology (Figure 6.1). As the collaborative initiative progresses, it is envisaged to incorporate other industries and additional reuse opportunities. Earlier in this chapter, the driver and barrier types were discussed based on the complete set of successful and unrealised inorganic by-product synergies in Kwinana. In Table 6.2, the drivers and barriers have been assessed for each of the promising synergy opportunities. The aim of the collaborative methodology is to eliminate the collective barriers faced by the individual companies and assess means to enhance the common drivers. The synergies that mostly benefit from a collaborative methodology are those opportunities which have diversified applications rather than one specific reuse application within another company. This can be explained by the common regulatory barriers, community exposure, and transportation issues experienced for these reuse options.

Table 6.5: Evaluation of Promising Inorganic By-Product Synergy Opportunities

Synergy #	Driven by Individual Companies	Driven by Collaborative Initiative	Benefits from Collaborative Initiative	Drivers and Barriers *							
				Regulation	Economics	Community	Technology	Transportation	Confidentiality Issues	Risk and Liabilities	Industry Priorities
1	ü				DB		DB	D	B	B	DB
2	ü				DB		DB				DB
3	ü	ü	ü	B	DB	B	D	B		B	D
4	ü	ü	ü	B	DB		D	B			D
5	ü	ü	ü	B	DB		D	B			D
6	ü				DB		B	D			D
7	ü	ü	ü	B	DB	B		B		B	D
8	ü				DB		B	D	B		D
9	ü	ü	ü	B	DB	B	B	B	B	B	B
10	ü	ü	ü		DB			?	B		B
11	ü				DB		B	D			B
12	ü		ü	B	DB			B			
13	ü				DB		B	D			
14	ü		ü	B	DB			B			
15	ü	ü	ü	?	DB	?	?	?			D
16	ü			B	DB	B		B		B	D
17	ü				DB		B	D			D

* D = driver / B = barrier

1. Use of high iron fraction bauxite sand for pig iron production
2. Use of high iron fraction bauxite sand for cement clinker production
3. Use of high iron fraction bauxite sand for agriculture and soil treatment
4. Use of high silica fraction bauxite sand for concrete aggregate production
5. Use of washed sand for general and road construction
6. Use of red lime for cement clinker production
7. Use of red lime for agriculture and soil treatment
8. Use of iron making slag for alumina refining
9. Use of iron making slag for agriculture and soil treatment
10. Use of iron making slag for niche applications (e.g. chemical production)
11. Use of fly ash for cement manufacturing
12. Use of fly ash for general and road construction

13. Use of bottom ash for cement manufacturing
14. Use of bottom ash for general and road construction
15. Use of gypsum for various applications (e.g. bricks, plasterboard, landfill liner)
16. Use of gypsum for agriculture and soil treatment
17. Use of gypsum for cement manufacturing

6.3.7 Producers Base

The assessment of available quantities (left column in Table 6.6) shows that a total of approximately 2.7 million tonnes per year of inorganic by-products are being produced by the Kwinana industries. Furthermore, an estimated 80 million tonnes of these materials are stockpiled from past operations on designated sites in and around the KIA (Bossilkov and Lund 2008a). These materials are available for reuse (with or without further processing) if the associated barriers can be overcome and their drivers be enhanced.

Table 6.6: Supply and Potential Local Demand for Inorganic By-Products in Kwinana (Bossilkov and Lund 2008a)

Inorganic By-Products in Kwinana	
Type	**Quantity**
Fly ash	25 ktpa + stockpile
Red sand	2,200 ktpa + Mt stockpile
Red lime	110 ktpa + Mt stockpile
Iron making slag *	225 kpta
Phospho-gypsum	1,300 kt stockpile
FGD gypsum	Unknown
Construction rubble	Mt stockpile
Cement kiln dust	15 ktpa + Mt stockpile
Bottom ash	4.5 ktpa + Mt stockpile
Foundry sand	15 ktpa
Lime kiln dust	100 ktpa + Mt stockpile

Future Construction Projects in Kwinana / Perth region	
Project	**Quantity**
James Point (stage 1)	300 kt sand 3,700 kt materials
Fremantle Outer Harbour (option 1)	15,400 kt fill 23,000 kt materials
Amarillo Satellite City (residential)	12,000 kt fill 800 kt road materials
Wungong Urban Water (residential)	16,500 kt fill 400 kt road materials
Latitude 32 (Hope Valley Wattleup)	Unknown
More than 10 other projects planned within Peel region (5 to 20 years)	

Total Estimated Required Quantities over 25 Year Period	
Clean fill	42,000 kt
Construction materials (mix)	25,000 kt

6.3.8 Customers Base

The initial market assessment carried out as part of the collaborative methodology revealed that the local building and construction sector has the largest potential to result in the utilisation of high volumes of inorganic by-products (e.g. direct reuse as a clean fill or concrete aggregate). Table 6.6 (right column) presents the results of a detailed market assessment for the building and construction sector in the Kwinana and Perth region. It shows that a staggering total of 42 million tonnes of clean fill and 25 million tonnes of construction materials are required for upcoming construction projects locally in the next 25 years. There is already a shortage of raw materials to meet this increasing demand. The market analysis clearly shows that the resource needs for these construction projects can easily be met by the inorganic by-products available in the KIA.

6.3.9 License to Operate

Earlier in this chapter it was outlined that government and community support for the reuse of inorganic by-products in diversified applications has not yet been forthcoming. However, there is an increasing awareness of the environmental impacts associated with the extraction of raw materials (e.g. quarry sand) and the fact that inorganic by-products are valuable sources of alternative materials. Through the collaborative Kwinana initiative, discussions with various governmental stakeholders (e.g. WA Department of Planning and Infrastructure, Department of Environment and Conservation) are being held to assess means for streamlining the regulatory approval processes so that there is a standardised review process. If implemented, this process will enable the sustainable reuse of inorganic by-products for specific applications (e.g. building and construction).

In the short term, the most immediate policy support requirement to foster further synergies is the development of standards and guidelines for reuse. These could be customised depending on the particular by-product material and reuse conditions. This would enable the safe reuse of materials and assist companies in showing that they have met the required regulatory standards. Although guidelines are being developed for land application of residues, other applications are also in need of guidelines (such as building and construction). For instance, the basis for guidelines could be the development of a classification system that consists of four to five categories based on contaminant threshold levels, with appropriate reuse options for each category (Harris 2007). The reuse options for the by-products would be dependant on the threshold levels and the risk involved in a particular reuse option. The development of such a system would also provide the structure for government to support industry in community communications and provide backing to industry where they have met the necessary standards for reuse.

6.3.10 Technology Base

As part of the technology base, the first priority is to find direct reuses for the inorganic by-products (e.g. clean fill). In addition, there is an opportunity to mix various inorganic by-products into 'superior' products with enhanced characteristics. This is a secondary priority for the collaborative Kwinana methodology. The challenge is to apply low cost beneficiation processes; otherwise the business case can not compete with traditional "virgin" resources. Clean fill and concrete aggregate are two example applications in the building and construction sector where direct reuse is most likely possible. A processing plant has been developed by the Alcoa Kwinana refinery to separate their red sand into a high iron fraction, high silica fraction, and mid fraction. This processing plant enables the characteristics of these separated fractions to meet the end-use requirements for various construction materials (e.g. filler, concrete aggregate, roadbase). Therefore, the plant enhances the potential for such materials to be reused in the construction sector (Cooling and Jamieson 2004).

The customised methodology discussed in this chapter is utilising the results from previous and parallel research on specific technical aspects related to the reuse of these by-products. A significant proportion of the parallel research is conducted through the Centre for Sustainable Resource Processing. This latter includes projects on magnetic separation of Alcoa sands and minerals separation from bauxite residues (complete list of projects is available from www.csrp.com.au).

6.3.11 Development and Implementation of Feasible Opportunities

It is anticipated that the development of regulatory standards will enable the reuse of high volumes of inorganic by-products in the KIA. At the moment these standards do not exist yet. Discussions with various governmental departments are being held to assess means for streamlining the regulatory approval processes so that there is a standardised review process. It must be noted that the application of the collaborative methodology with the industries, government, Kwinana Industries Council, and community is ongoing. The development of the reuse standards will take time to ensure sustainable outcomes for all parties involved.

6.4 Conclusions from Application of Methodology

This chapter has shown that significant potential exists for the establishment of large scale reuse of inorganic by-products available within the KIA. A coordinated stakeholder methodology is being facilitated and applied which targets the realisation of a number of iconic and short-term reuse opportunities that have both a good business case and sustainability benefits. The synergies which predominantly benefit from the collaborative Kwinana methodology are those opportunities which have dispersed and diversified applications rather than one specific reuse application with another company. This can be explained by the common regulatory barriers, community exposure, and transportation issues experienced for the dispersed reuse options.

For all inorganic by-product synergy opportunities presented in this chapter there are both tangible operating benefits as well as less tangible benefits, such as reputation, environment or community. The types of benefits can vary greatly and often go well beyond the conventional business case benefits. Resource security and efficiency, diversion from landfill/stockpile, lower operational costs, reduced extraction of "virgin" raw materials, and employment are key benefits from inorganic by-product synergies in Kwinana.

The drivers, barriers, and triggers for inorganic by-product synergies in the KIA appear to fall in nine broad categories: regulation, economics, community, technology, transportation, confidential and commercial issues, risk and liabilities, industry focus and priorities, and region-specific issues. It is clear that a wide range of drivers and barriers exist which are influenced by diverse set of stakeholders (e.g. companies, regulators, community). The complete set of drivers, barriers, and trigger events, rather than one specific aspect, determines the business and sustainability case of an inorganic by-product synergy, and hence are key to the implementation of a reuse project. Overall, it is clear that there is no "one-size-fits-all" approach to develop reuses of inorganic by-products; each synergy is unique in terms of its drivers, barriers, business case, and sustainability benefits. The cleaner production framework proved to be an effective and flexible mechanism to accommodate these requirements and uncertainties applicable to inorganic by-products synergies. After all, the cleaner production framework is based on a generic continuous improvement PDCA Deming cycle (Plan-Do-Check-Act) (see Section 5.1).

Kwinana industries are experiencing obstacles in getting governmental approvals for the reuse of their inorganic by-products. Recent developments indicate that the local and state governments have an increasing awareness and understanding of the resource value of the large volume inorganic by-products produced within the KIA. Discussions with various government departments are being held to assess means for streamlining the regulatory approval processes so that there is a standardised review process. A review of international experiences and practices has revealed that inorganic by-products are widely accepted and reused as alternative raw materials internationally for building and construction, agriculture, and resource recovery. The regulatory frameworks and reuse standards being applied in numerous countries (e.g. USA, The Netherlands, France, Sweden, Denmark, Germany) encourage, and in some cases even enforce, the reuse of inorganic by-products. This is not yet the case in Western Australia where the lack of regulatory reuse protocols prevents or delays the implementation of such reuses on a large scale and routine basis.

Up to 3 million tonnes of inorganic by-products are produced each year by the Kwinana industries, while an estimated 80 million tonnes of these materials are already stockpiled from past operations. A market assessment revealed that about 65 million tonnes of clean fill and other construction materials are required for future local construction projects. There is already a shortage of raw materials to meet this increasing demand. The material needs for these upcoming projects can easily be met by the inorganic by-products available in the KIA. As shown in this chapter, their realisation would provide a range of sustainability benefits to the region, industries and the communities.

As a final note, it must be acknowledged that the collaborative work with the industries, government, KIC, and the community is ongoing. The stakeholder engagement processes and development of the reuse standards will take time in order to ensure a sustainable solution for the large volume inorganic by-products in Kwinana.

7 METHODOLOGY TO ADVANCE WATER UTILITY SYNERGIES

This chapter is based on the journal article: Van Beers et al. (2008).

7.1 Introduction

Due to declining levels of groundwater and stored water in Perth Metro dams, fresh water has become a scarce resource, a situation that is likely to continue for the next decades. Runoff into dams has been reduced by 40-50% since 1975 because of decreased rainfall. This has impacted domestic and industrial water users by directly reducing the available fresh water resources and indirectly restricting potable (scheme) water available to industry. The State Water Strategy includes a water reuse target of 20% by 2012 (GoWA 2003). The Western Australian government will require major water users to demonstrate their responsible use of water by setting up and implementing water resource management plans. As a result, there is an urgent need to further investigate the opportunities for improving water efficiency and reducing effluent disposal in the Kwinana Industrial Area.

Water consumption and effluent disposal by Kwinana businesses are key environmental issues addressed by the KIC. Over the past years, significant progress has been made towards the improvement of water consumption and effluent disposal in Kwinana, both at the company level (e.g. on-site water efficiency assessments at various KIC member companies) and at the regional level (e.g. Kwinana Water Reclamation Plant). Individual companies had achieved major water savings prior to engaging in water synergies, e.g. Tiwest Pigment Plant, CSBP, and BP Refinery (DEH 2001a, 2001b; WASIG 2005).

This chapter presents the methodology developed to identify and evaluate water synergy opportunities, including the results from its trial application in the KIA.

7.2 Developed Methodology

Figure 7.1 presents the methodology applied to arrive at feasible water synergy opportunities for the KIA. Each stage of the method is discussed in the following subsections. The interrelation between the customised methodology and the cleaner production framework is detailed in the left column of Figure 7.1.

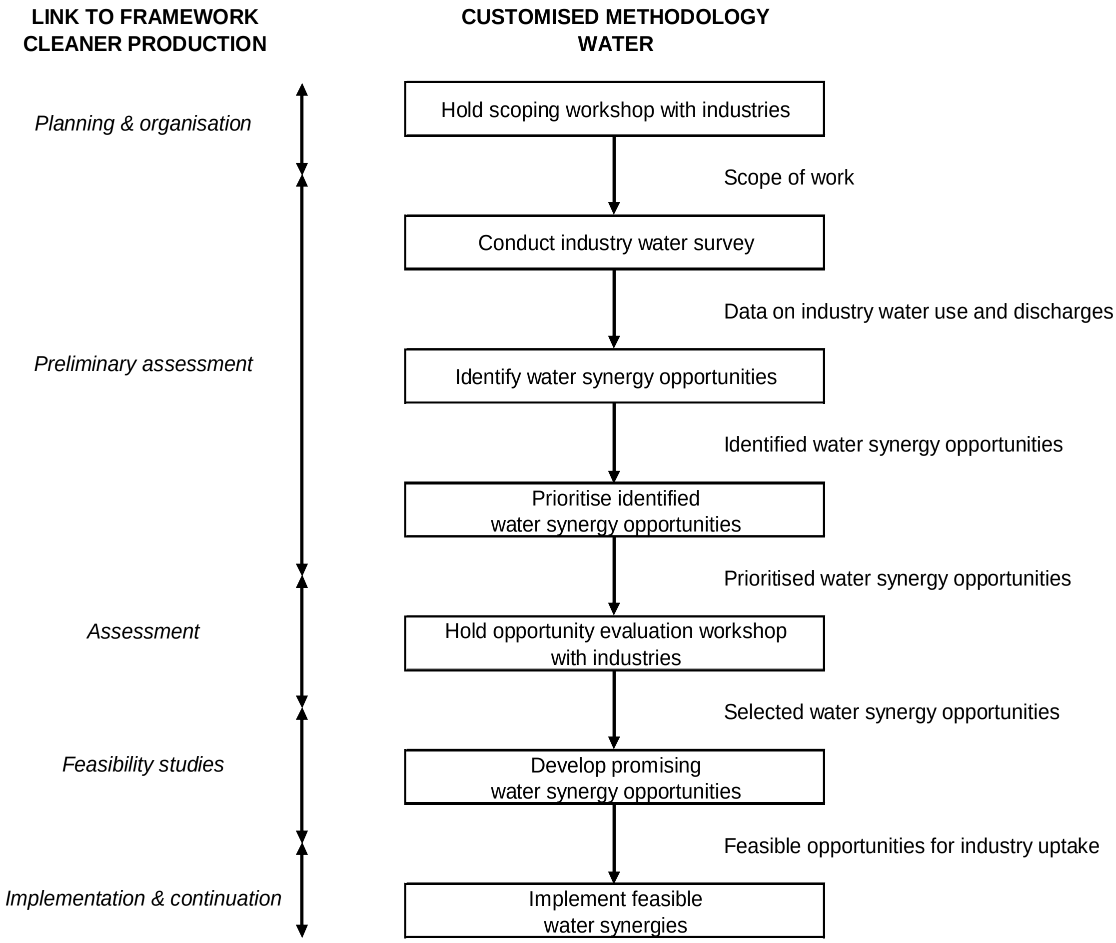

Figure 7.1: Customised Methodology to Advance Water Synergies

As outlined in Chapter 5, the cleaner production framework (Figure 2.1) was used as a template to develop the customised methodology to advance water synergies in the case-study area (Kwinana). The methodology, as presented in this chapter, was developed in close collaboration with the Kwinana industries and the KIC. Each element of the cleaner production framework was customised to cater for the specific industry needs and available qualitative and quantitative water data in the region. As a result, the customised methodology for Kwinana has a strong focus on the identification and preliminary evaluation of water synergy opportunities, rather than detailed economic and technical modelling. It was believed that the industries themselves were better placed to undertake these detailed assessments once promising opportunities had been identified (given their intimate understanding of their process requirements, but also due to confidentiality and commercial issues).

The justification for choosing the cleaner production framework as a template for developing the customised methodologies to advance water (and energy and inorganic by-product) synergies is provided in section 2.10.4.

The author of this thesis acknowledges that various methods exist for the identification and evaluation of possible water resourcing opportunities, including Integrated Resources Planning (Turner et al. 2006; Turner et al. 2008), One-to-Five (Energetics n.d.), and Sydney Water Every Drop Counts Business Program (Sydney Water n.d.). Rather than applying sophisticated and complex computing models, it was decided, in close collaboration with the KIC and its industry members, to cater the water synergies methodology specifically to the needs of the Kwinana industries in order to drive forward water synergies in a pragmatic and systematic way.

The following models were considered to be incorporated in the methodology discussed in this chapter:

- Integrated Resources Planning (Turner et al. 2008): This approach, also referred to as 'least cost planning', aids best practice water planning and management for urban developments. It requires detailed water demand forecasting for a specific region and the consideration of a full range of both supply-side and demand-side options to be assessed. It also requires the use of review and evaluation processes to enable adaptive management in the decision making process. While it is a comprehensive and valuable approach to assist water utility and service providers for urban developments, it has limited use for the purpose of this research where the focus is on the identification and development of water reuse opportunities between industries. However, it is interesting to note that the Integrated Resource Planning approach aligns, in broad terms, with the cleaner production framework – i.e. step 1: plan the overall process, step 2: analyse the situation, step 3: develop the response, and step 4: implement response.

- One-2-Five® (Energetics n.d.): Energetics' One-2-Five® Water is a diagnostic tool that assesses the state of a company's internal systems and procedures for managing water costs and risks across the organisation. The tool can be used to track improvements in business systems and provide roadmaps for advancing towards world's best practice in water (and energy) management. It engages senior decision-makers in a process with a strong business case focus. One-2-Five® Water is a commercial tool owned by Energetics which is not in the public domain. Therefore it has limited use for the purpose of this PhD research.

- Sydney Water Every Drop Counts (EDC) Business Program (Sydney Water n.d.): The EDC Business Program works with organisations in the Sydney region to assist these in reducing their water consumptions and associated costs. The (EDC) program uses two management tools – One-2-Five® Water (see above) and Water Achiever®. The latter is a simplified version of the One-2-Five® Water tool, and is designed for companies with simpler management structures and that consume less water. It provides specific actions for the companies to ensure that main parts of good water management are covered. The tools are provided free of charge to participants of the EDC Business Program. The main focus of these two management tools is on eco-efficiency opportunities, while not so much on establishing water reuses (synergies) with neighbouring industries (the topic of this thesis).

7.2.1 Scoping Workshop

An initial workshop with the Kwinana industries was organised to discuss the status quo of water consumption and disposal in the KIA, and to identify opportunities for further enhancement of efficient water use and regional synergies in the area. One of the workshop recommendations was to conduct a detailed analysis of water inputs and outputs for the industries' processes and the Kwinana region as a whole, and work with the industries to identify and development promising water synergy opportunities. The workshop provided the foundation for the development of the customised methodology presented in this chapter (Figure 7.1).

7.2.2 Industry Water Survey

An initial survey conducted with 30 Kwinana industries included data of their total water use and discharge quantities. Based on this survey it was possible to select the top ten water consuming industries for which to construct detailed water balances. These water balances were compiled based on existing company reports and discussions with site staff, and included the quantities and qualities of separate water flows going into and out of the companies.

7.2.3 Identification of Opportunities

Based on the water balances constructed for each company, all available water input and output flows were linked based on:

- Water needs of individual industries;
- Distances between companies;
- Quantities and qualities of the water flows.

There were numerous ways to connect the water sources (companies that discharge water in various quantities and qualities) and water sinks (companies which could potentially use another company's water output). To accommodate these variations, each water synergy identified was mapped in a so-called 'source/sink diagram' (framework with fictional example provided in Figure 7.2). This diagram incorporates the basic information that affects the feasibility of any water synergy project such as available and required water quantities and qualities, possible water treatment technologies, and distance between the two companies.

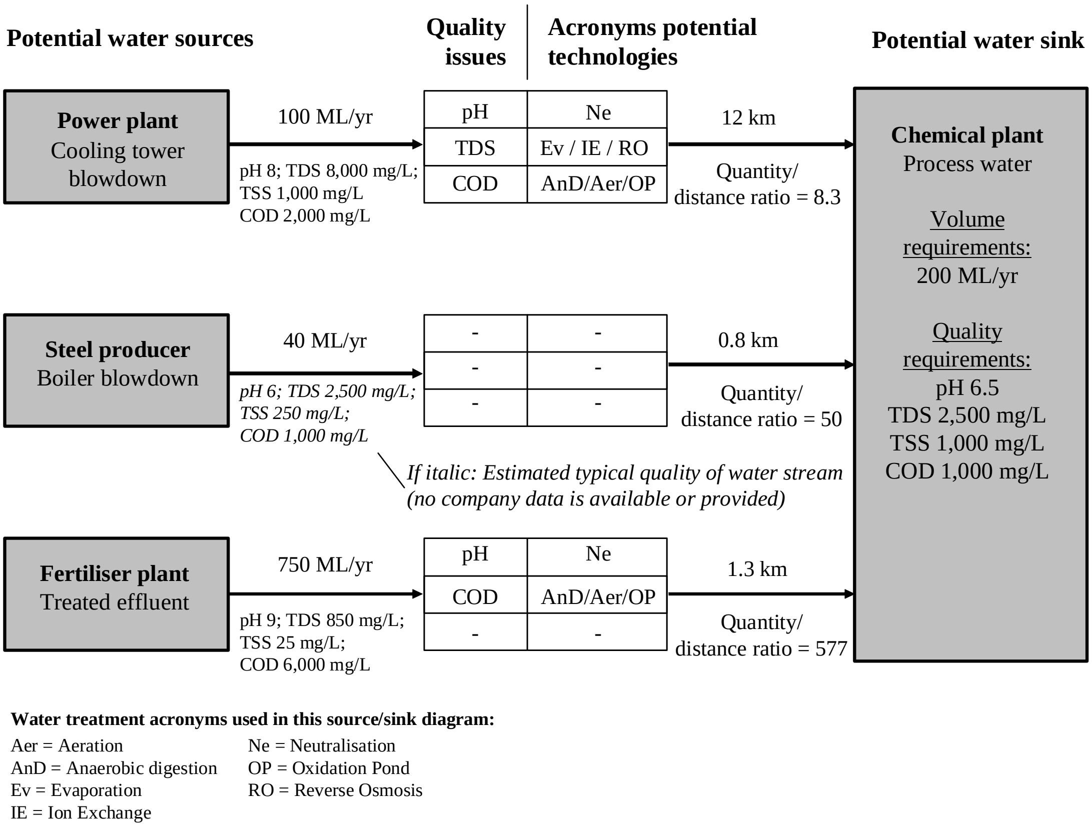

Figure 7.2: Fictional Example of Water Synergy Source / Sink Diagram (Van Beers et al. 2008)

The identification of water synergies was based on the matching of water input/output flows (Figure 7.2) and focused on three key areas:

1. Exchanges of water between industrial operations;
2. Joint treatment of water; and
3. Joint industry storage of water.

7.2.4 Prioritisation of Opportunities

A central aim of this work was to assist the Kwinana industries in achieving a greater number of water synergies in a technically and economically feasible way. As outlined in previous section, there were various options to connect the water users (sinks) and suppliers (sources). In order to facilitate decision making on which potential water synergies to take forward, a priority assessment was applied to the water synergies identified.

All water synergy opportunities have been evaluated separately, based on the criteria of quality match, quantity/distance ratio, and potential to be an icon project in Kwinana. Table 7.1 presents the applied rating system for this evaluation, using a scale from 1 ("not so good") to 4 ("best"). The total rating is the sum of the three individual ratings. The water synergies were categorised by sink (water users) with their potential water suppliers sorted by total rating from highest to lowest value. The highest-scoring synergies were regarded as candidates that are clearly preferable to those near the bottom of the table. In contrast, marginal differences in scoring are not substantial to guide decision-making.

Table 7.1: Ratings for Priority Assessment on Water Synergy Opportunities

Criteria	Rating			
	1	2	3	4
Rating quality match (which affects likely treatment costs)	Major quality issues, extensive treatment required, difficult	Moderate quality issues, and moderate treatment required, moderate efforts	Minor quality issues, minor treatment required, relatively easy	No quality issues, direct reuse possible, very easy
Rating quantity (ML/yr) / distance ratio (km)	Quantity/distance ratio < or = 50	Quantity/distance ratio 51 - 250	Quantity/distance ratio 251 - 500	Quantity/distance ratio > or = 500
Rating as icon project, based on volume of reusable water and other likely benefits of water synergy	Synergy has very limited potential to make significant sustainability contributions to companies and KIA	Synergy has some potential to make significant sustainability contributions to companies and KIA	Synergy has moderate potential to make significant sustainability contributions to companies and KIA	Synergy has large potential to make significant sustainability contributions to companies and KIA

7.2.5 Opportunity Evaluation Workshop

An opportunity evaluation workshop was organised to bring together the largest water consuming industries in Kwinana to review and consolidate the findings of the detailed water input/output mapping (van Beers and van Berkel 2005b). Prior to the workshop, a scoping report on the identified and prioritised water synergy opportunities was sent to all workshop participants. The overall aim of the workshop was to review the potential water synergy opportunities and identify those opportunities that are most likely to be feasible on the basis of currently available information.

The structure of the workshop discussion is presented in Figure 7.3. The discussion session was divided into two main components. The purpose of the first part was to screen the water synergy opportunities based on likely achievability and business / sustainability benefits, and get overall industry feedback. The second part of the workshop session was to discuss the further development of selected water synergies, including outstanding issues, and ways to improve and combine synergies.

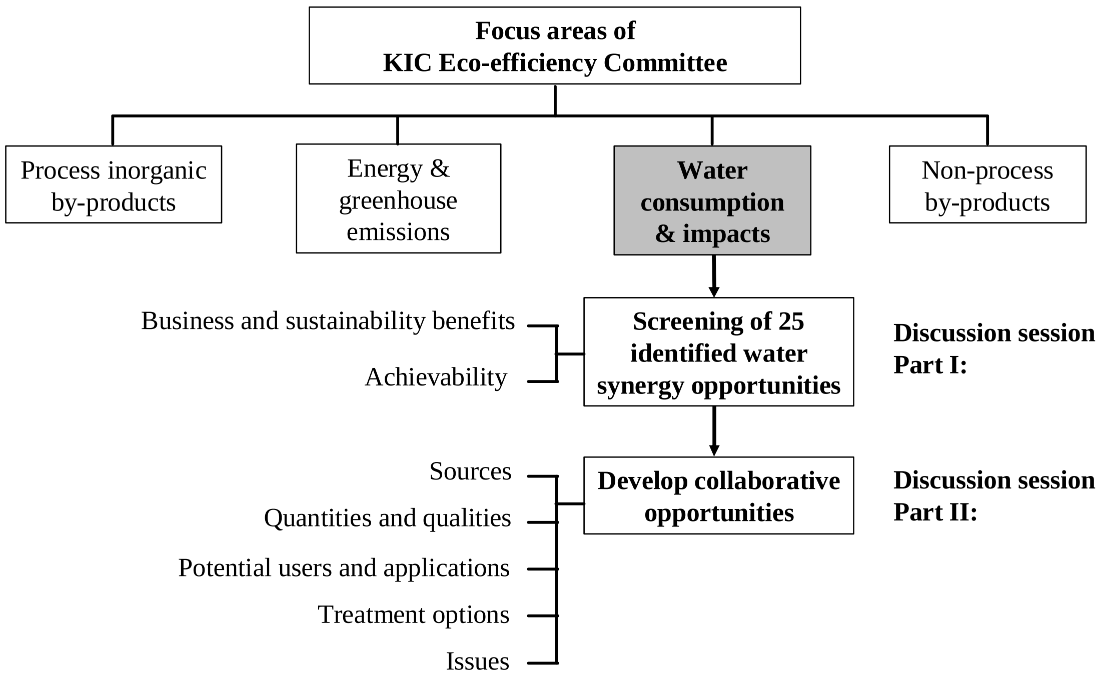

Figure 7.3: Structure Workshop Discussions on Water Synergy Opportunities

7.2.6 Development and Implementation of Feasible Opportunities

The feasibility and implementation phase consists of providing practical assistance to the Kwinana industries and the KIC with the development and implementation of promising synergy opportunities. The main focus was on the water opportunities which have been prioritised (as discussed in previous subsection) and subsequently selected by the Kwinana industries based on their anticipated business case and sustainability benefits.

7.3 Results from Application of Methodology

7.3.1 Industry Water Survey

Figure 7.4 provides the total input and output water quantities of 30 Kwinana industries. Due to confidentiality issues, water consumption data for individual industries can not be presented and discussed here. The figure shows that the industries consume more than 35 gigalitres of fresh water per year. Scheme (potable) and bore water represent about 18% and 39%, respectively, of the fresh water input. External sources (the existing water synergies) account for about 7% of the total fresh water inputs. About 24% of the water outputs are evaporative losses, and an additional 23% of the total water output is unaccounted for due to evaporation, use in product, lack of monitoring, and data inaccuracy. These values indicate that significant scope may exist for condensate recovery and other measures to reduce water losses to the environment, and also for enhancing water monitoring in the KIA.

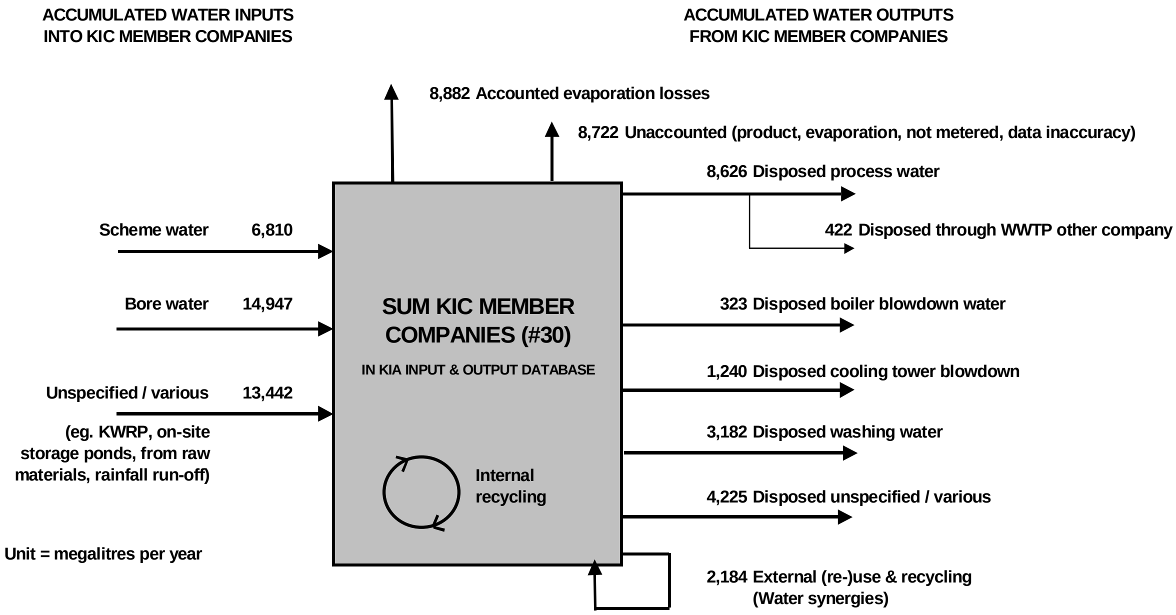

Figure 7.4: Water Input and Output Diagram for the Kwinana Industrial Area[3]

[3] *Notes on Figure 7.4:*

7.3.2 Identification of Opportunities

A total of 25 water synergy opportunities were identified through the methodology. A source/sink diagram was constructed for each synergy opportunity identified (see Figure 7.2). Table 7.2 presents a summary of the potential water synergies. As shown in this table, the options cover a wide range of reuses. No opportunities were identified for joint storage of water.

Table 7.2: Summary of Identified Water Synergy Opportunities (van Beers and van Berkel 2005b)

Water Synergy Opportunities in Kwinana	# Identified	Comments
Water Exchanges between Industries*		
§ External reuse of effluent as process water	7	Quality requirements (e.g. TDS, pH, metals) for process water vary greatly amongst industries
§ External reuse of effluent as washing water	2	Careful consideration must be given to quality issues as washing / cooling water is discharged into sensitive marine environment
§ External reuse of effluent as cooling water	4	
§ External reuse of effluent as reverse osmosis feedwater	2	Community perception against the use of industrial water as input to desalination plant to produce dinking water
§ External use of demineralised water	2	High quality water source
§ External use of bore water	1	Synergy is related to allocation of bore water quantities to individual industries, this is outside scope of this project
Joint Treatment of Water		
§ Effluent treatment at other company	3	Some Kwinana companies have excess treatment capacity, and could potentially

§ Presented data are sums of provided data from companies participating in the Kwinana Synergies Project (31 companies).
§ Data above does not include seawater, only fresh water.
§ Data above includes HIsmelt data (stage 1).
§ Water Corporation data are not included as this will result in misleading indicators for water. This is because Water Corporation facilities supply and treat large volumes of domestic water from outside the KIA.

Water Synergy Opportunities in Kwinana	# Identified	Comments
		treat other companies' effluent
§ Joint treatment and supply facility	4	Aims at zero discharge of industrial effluents in Kwinana (treatment and reuse of all effluents)
Joint Storage of Water		
None identified	0	
Total	**25**	

* Effluent refers to the wide range of wastewater types available in Kwinana (e.g. boiler blowdown, cooling tower blowdown, treated industrial and municipal effluent, reverse osmosis concentrate, etc.).

7.3.3 Evaluation of Opportunities

The identified water synergy opportunities were discussed in an opportunity evaluation workshop with the Kwinana industries. A summary of the evaluated potential water synergies is provided in Table 7.3. The workshop resulted in a shortlist of 11 one-on-one water synergy opportunities (direct between two companies) recommended for further consideration by the companies involved. In addition, nine synergies should also be considered as part of collective water synergy projects between multiple companies. These were grouped into four integrated water projects for Kwinana:

1. <u>Reuse of treated industrial effluents as separate streams:</u> The discharge of treated industrial effluents is a significant source of water loss in the KIA. There is scope to assess how these industrial effluents streams could be reused (with or without treatment) by the various industries and thereby improve the overall water efficiency in the area.

2. <u>Reuse of water from the ocean outlet landline:</u> The Sepia Depression Ocean Outlet Landline (SDOOL) discharges municipal and industrial treated effluents approximately four kilometres offshore, reducing water discharges into Cockburn Sound (a sensitive marine environment). There is merit in pursuing a collective Kwinana effort to further reuse this aggregated water flow, with water treatment according to the specific requirements of the

Kwinana industries and utilising existing infrastructure (e.g. pipeline, water treatment plants) as much as possible.

3. Further development of the Kwinana Water Reclamation Plant (KWRP): The KWRP is briefly described earlier in this chapter. The existing plant is designed to facilitate an extension of the current capacity of 17 ML/day to 22 ML/day. When this plant has reached its maximum design capacity, there is scope to construct a second reclamation plant. The further development of the KWRP is being assessed by the Water Corporation.

4. Reuse of boiler blowdown from power generation: Relatively large volumes of boiler blowdown are generated from power generation in Kwinana (two major power stations and two cogeneration plants are located in the area). These boiler blowdown qualities are potentially well suited for reuse as a cooling or process water by other Kwinana industries.

Table 7.3: Summary of Evaluated Water Synergy Opportunities (van Beers and van Berkel 2005b)

Water Synergy Opportunities in Kwinana	**# Identified**	**# Selected***	
		As One-on-one Company Synergy	**As Collective Synergy**
*Water exchanges between industries**:*			
§ External reuse of effluent as process water	7	4	5
§ External reuse of effluent as washing water	2	2	0
§ External reuse of effluent as cooling water	4	0	2
§ External reuse of effluent as reverse osmosis feedwater	2	0	1
§ External use of demineralised water	2	2	0
§ External use of bore water	1	0	0
Joint treatment of water:			
§ Effluent treatment at other company	3	3	0
§ Joint treatment and supply facility	4	0	1
Joint storage of water:	0	0	0
Total	**25**	**11**	**9**

* Some of the identified water synergies were selected for further assessment as one-on-one company synergies as well as collective Kwinana synergies (involving more than two companies).

** Effluent refers to the wide range of wastewater types available in Kwinana (e.g. boiler blowdown, cooling tower blowdown, treated industrial and municipal effluent, reverse osmosis concentrate).

7.3.4 Development and Implementation of Feasible Opportunities

As outlined earlier in this chapter (Section 7.2), it became clear that the industries themselves were best placed to undertake detailed feasibility assessments for promising opportunities. Therefore, the research efforts focused on providing assistance to industries as required to progress the short-listed one-on-one company synergies, and scoping ways forward for the further development of the four collective water synergy opportunities. Critical to the success of the research is liaison with key water consuming companies to achieve their participation in a collaborative methodology to water synergies and alternative water sources. In addition, the proposed collaborative research work should meet the research needs of industry (e.g. facilitation between water producing and consuming companies).

It is noted that the research presented in this thesis is directed towards achieving regional synergy opportunities through the application of the cleaner production approach. Through discussions with the Kwinana Industries Council and their industry members, it was decided to focus the efforts on practical research assistance to the industries to increase their resource (water) efficiencies and reduce wastewater disposal, rather than compiling (theoretical) computational models to map water uses and subsequent benchmarking exercises in the Kwinana Industrial Area.

An example of a synergy that is being implemented by the Kwinana industries is the treatment of oily wastewater from the Kwinana Nickel Refinery by the BP Refinery. An example of a future synergy with promising prospects for implementation is the supply of treated effluent from CSBP Chemical Plant to the Kwinana Nickel Refinery (at least five years away). There is a commitment from the industries and KIC to implement further regional synergies and thereby enhance the sustainability of the KIA by increasing resource efficiencies and reducing wastes and emissions.

In addition to the short/medium-term efforts reported here the KIC is leading another initiative to identify sustainable options for water supply (various sources and quality), wastewater reuse and disposal for a 15 year planning horizon (2006 – 2021) (KIC Water Planning Study, (KIC 2007). This study recommends a number of preferred water sources based on available quantity and costs, including groundwater from other groundwater areas, Water Corporation treated wastewater, aquifer recharge of stormwater, and also the water synergies identified as part of the research presented in this chapter. Based on the outcomes of the Water Planning Study, the KIC will consider the future work in close cooperation with its members and other stakeholders (e.g. government departments and community groups).

7.4 Conclusions from Application of Methodology

Fresh water has already become a scarce resource as a result of declining levels of groundwater and water stored in Perth dams. This is likely to result in the costs of water increasing over time, and also in increasing external pressure to further reduce fresh water consumption. Over the past decade, significant progress has been made towards the improvement of water consumption and disposal in the Kwinana region, both at the company level and at the regional level. The efforts to secure a sustainable water use on the short/medium term (e.g. water efficiency and regional synergies) and long-term (such as the KIC Water Planning Study) show that a diversity of solutions are being explored, evaluated and, if found feasible, implemented by the Kwinana industries.

This chapter revealed that many and diverse water synergy opportunities still appear to exist in the case study area. The development and trial application of the methodology (as presented in this chapter) has assisted the industries and the KIC with the identification and development of promising water synergies. The author acknowledges that various tools could have been applied to assist with the identification, prioritisation, and development of water synergies in the KIA (e.g. those addressed in Section 7.2). The aim of this research is to investigate the effectiveness of using the cleaner production framework (Figure 2.1) as a basis for customised methodologies for advancing water (and inorganic by-products, and energy) synergies in heavy industrial areas. The water synergy methodology, as presented in this thesis, has been developed using this framework and build upon the specific research needs and interests of the local (Kwinana) industries. It is outside the scope of this thesis to apply a whole range of specialised tools available in various formats and configurations. The key message is that the cleaner production framework is a valuable and effective overarching approach to drive the (water) synergy development process from initiation (planning) to the eventual implementation of feasible opportunities. Overall, the research findings confirm that there is no “one-size-fits-all” approach for synergy development. The cleaner production framework proved to be an effective and flexible mechanism to accommodate these requirements and uncertainties. The type and level of assistance provided depends entirely on the specific research needs of the involved industries. Significant progress has been made so far to further develop a set of promising new synergies. The challenge for the research is to facilitate the implementation of one or more synergies. Strong commitment from the industries and the KIC will assist in achieving this goal. The implementation of a number of promising synergies is anticipated for the near future.

8 METHODOLOGY TO ADVANCE ENERGY UTILITY SYNERGIES

This chapter is based on the journal article: Van Beers and Biswas (2008).

8.1 Introduction

Energy is a key issue in Australia and subsequently also in the Kwinana Industrial Area, where the major energy consuming industries consume up to 80 PJ/yr of energy in their processes. The introduction of mandatory energy opportunity assessments for large users (> 0.5 PJ/yr) and climate change policies are expected to accelerate the implementation of energy conservation in Australia (DITR 2006a; PMC 2007; Planet Ark 2007). Moreover, increased pressure on water usage reduces its availability for process cooling and heat discharge. The development of advanced and efficient technologies could provide greater and more diverse opportunities for energy recovery. Therefore, it is pertinent to investigate the technical, economical, and environmental potential of energy efficiency and recovery opportunities in the KIA.

The chapter describes the customised methodology developed to identify and evaluate synergy opportunities utilising energy releases from the industries operating in the Kwinana Industrial Area (e.g. flue gases, waste steam, hot water). The results from the methodology application in the Kwinana case-study are then discussed. A summary of the key findings is presented at the end of the chapter.

8.2 Developed Methodology

Figure 8.1 outlines the customised methodology developed to advance energy utility synergies in Kwinana. As part of the method, potential recovery opportunities have been identified and preliminary technical, economic, and environmental assessments have been carried out. Each step within the methodology is discussed separately in the following subsections. The interrelation between the cleaner production framework and the customised methodology for energy synergies is detailed in the left column of Figure 8.1.

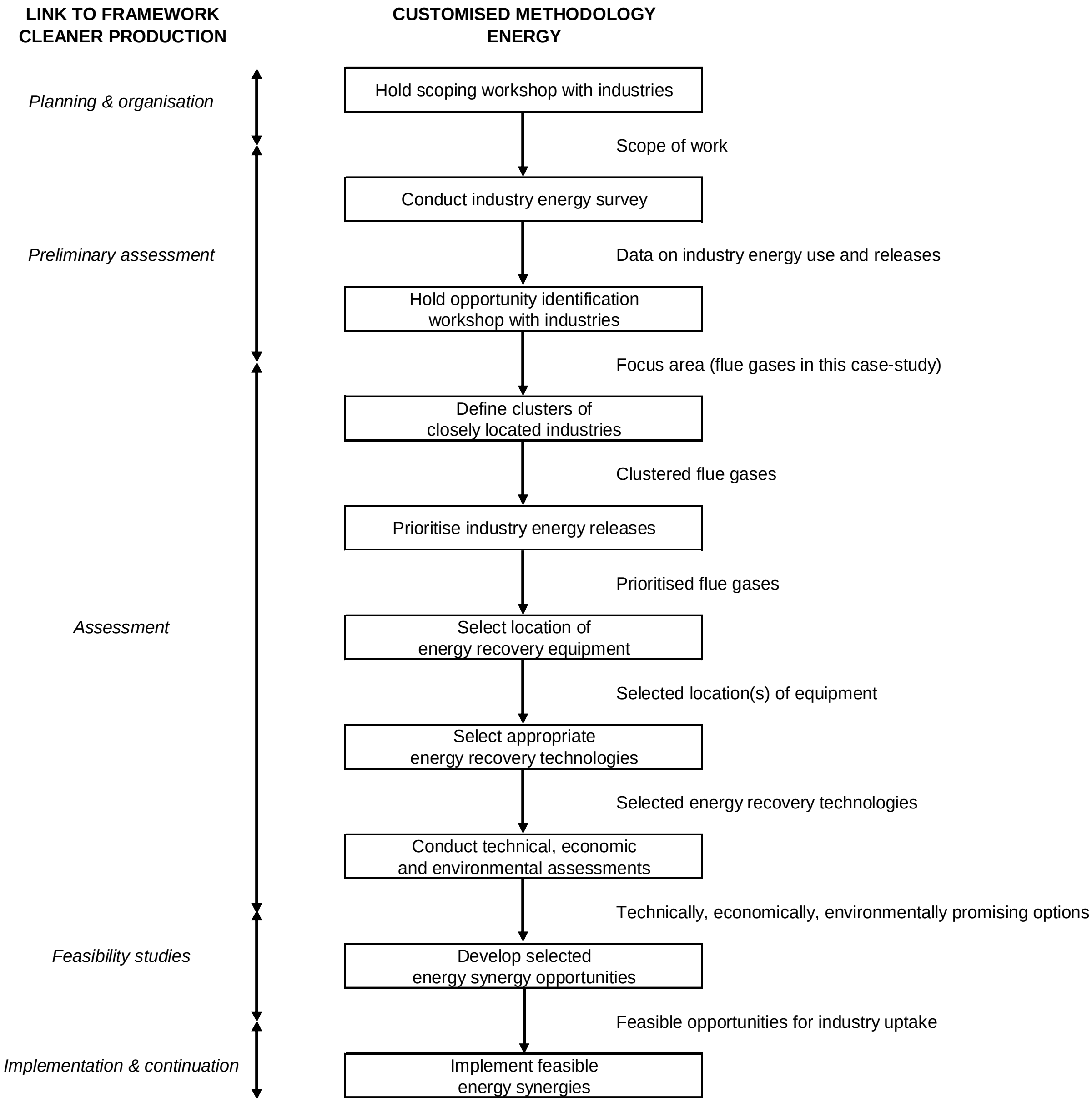

Figure 8.1:Customised Methodology to Advance Energy Synergies

8.2.1 Scoping Workshop

A scoping workshop was held with the KIC industry members to promote and plan the implementation of economically viable energy synergy opportunities among companies in the KIA. The workshop identified the need for more detailed quantitative and qualitative analysis of company energy uses and releases, and increased knowledge-sharing of best practice and experience in energy efficiency and management. Similarly as for the methodology to advance water synergy opportunities (see Chapter 7), the scoping workshop provided the basis for the development of the customised methodology for energy synergies (Figure 8.1).

8.2.2 Industry Energy Survey

In order to obtain detailed quantitative and qualitative analysis of company energy uses and releases, a survey was conducted with the largest energy consuming industries in Kwinana. The purpose of the survey was to (1) assess the energy sources and quantities used by the companies, (2) assess how these energy sources are used, (3) identify those processes releasing waste heat currently not utilised, and (4) aid the preliminary assessment on the energy quantity available for potential recovery. The survey assessed energy losses from flue gases, hot water, air, steam, and manufactured hot products.

8.2.3 Opportunity Identification Workshop

Following up on the energy survey, a workshop was organised to consider ways to enhance energy efficiency in the KIA by bringing together the Kwinana industries to review and consolidate the results from the energy survey and to agree on the best way to proceed. The decision was made at the workshop to focus the research efforts on energy recovery on flue gases only, and not on other energy losses at this stage (e.g. steam, water, products). This was due to the limited recovery potential for these latter energy losses in terms of energy content and temperature (Van Beers 2006).

8.2.4 Identification of Clusters of Closely Located Industries

One of the main variables which affects the feasibility of energy recovery is the distance between the point of emission and the energy recovery technology. This is particularly applicable to collaborative recovery opportunities (regional synergies) where energy is transported from one company to another or to a central collection point. Collaborative energy recovery opportunities may exist between two or more industries in close proximity (up to one kilometre), rather than between companies located far from each other. For this reason, the KIA was divided into seven clusters of industries (see Figure 8.2). Collaborative opportunities were assessed within each cluster, but not between industries located in different clusters. The available flue gases and the distances between the companies in each cluster were mapped using a standardised framework (Figure 8.3).

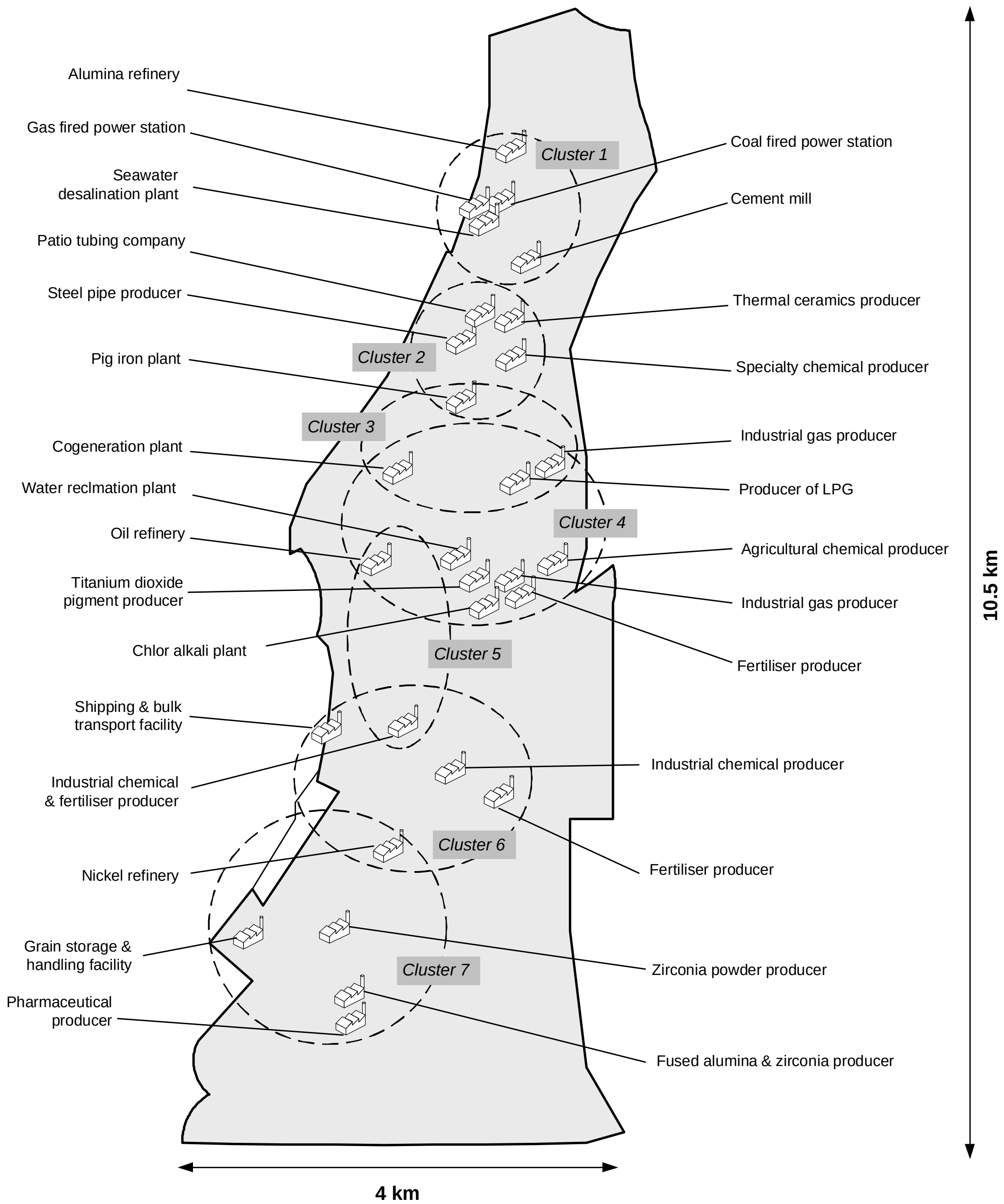

Figure 8.2: Location of Companies and Defined Clusters in the Kwinana Industrial Area. The grey coloured area represents the Kwinana Industrial Area

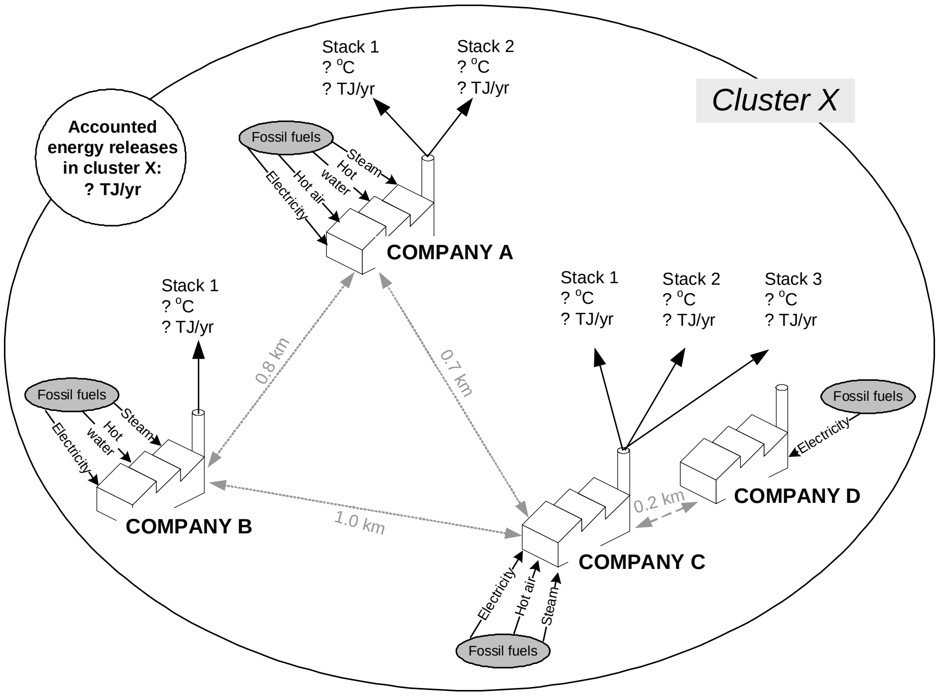

Figure 8.3: Framework of Industry (Flue Gas) Cluster – Fictitious Example

8.2.5 Selection of Priority Energy Releases (Flue Gases) within the Clusters

The feasibility of any energy recovery project is primarily determined by the temperature of the energy release, and secondarily by the total amount of recoverable energy (in terms of TJ/yr). All flue gases from participating Kwinana industries have been prioritised, on the basis of their temperature (°C) and their energy content (TJ/yr). High priority flue gases are those with higher temperatures and higher total energy contents while low(er) priority flue gases are the ones in the lower temperature ranges and low total energy contents.

8.2.6 Selection of Location for Energy Recovery Equipment within the Clusters

Within each cluster, there may be different pathways for reusing energy between the industries. The challenge was to keep the required transportation distances to a minimum. It does not make good business sense to consider collaborative energy recovery options where energy needs to be transported over large distances.

For collaborative energy recovery opportunities, two locations were considered for the energy recovery equipment:

- Located close to the largest flue gas emitter, for example heat exchangers in the stacks;
- Located between the two (or more) industries, for example an organic Rankine cycle fed by pre-heated working liquids from nearby companies.

8.2.7 Selection of Appropriate Energy Technologies within the Clusters

A selection of energy recovery technologies was considered as part of the methodology. The selection was based on the capacity (MW) of available technologies and their ability to utilise energy from flue gases in different temperature ranges. Based on these criteria, heat exchanger, waste heat boiler, economiser, Kalina cycle, organic Rankine cycle and conventional combined cycle were considered. For example, a conventional combined cycle was considered to source heat from flue gases with temperatures over 300^{o}C while a Kalina cycle can also utilise low-grade heat sources under 300^{o}C.

Some other alternative technologies (such as thermo-photovoltaics and thermal pyro-electrics) were not assessed, because these are still in their development stage and therefore not yet commercially attractive. In addition, their capacities are not yet sufficient to recover a signification fraction of the energy embedded in the flue gases in Kwinana.

The technical viability of insulated piping has been assessed to transport energy from the point of energy release (e.g. flue gas stack) to its targeted reuse application. Hot liquid was selected as the preferred medium for energy transportation because of the lower energy losses compared to hot air (Dartnall 2006). Heat pipes and phase change materials were not selected for this work as these technologies are not suitable commercially for transportation of significant energy quantities over large distances (100 metres or more) (Transterm 2006).

8.2.8 Detailed Assessments

8.2.8.1 Technical Assessments

The next step was to assess the technical potential of the energy recovery options identified in order determine which options could result in significant energy savings. The estimated efficiency of the technology was multiplied by the energy content of the flue gases for determining the energy recovered. Utilising the specific heat, estimated input temperature and energy content, the outlet temperature was estimated. The preliminary technical assessments included both best-case scenarios (using favourable estimates on technology efficiencies) and worst-case scenarios (using less favourable efficiency estimates).

A standardised framework was used to conduct the preliminary technical assessments for all identified on-site and collaborative recovery opportunities (Figure 8.4). A summary of the formulas applied and assumptions used to conduct the technical assessments for each technology option is provided in Appendix 4.

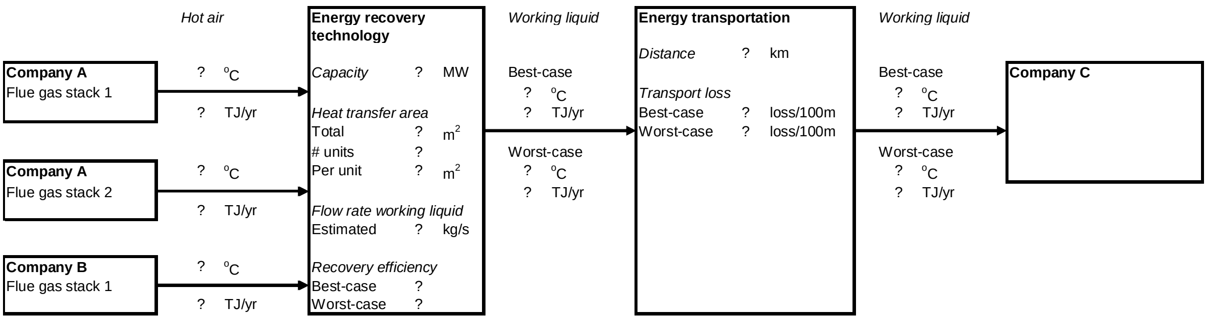

Figure 8.4: Framework of Technology Assessment for Kwinana Flue Gases

8.2.8.2 Economic Assessments

The method of Net Present Value (NPV) was used to assess the economic feasibility of technically promising recovery opportunities in both best-case scenarios (using favourable cost estimates) and worst-case scenarios (using less favourable cost estimates). NPV is a standard financial method in capital budgeting – the planning of long-term investments. Using the NPV method, a potential investment project should be undertaken if the present value of all cash inflows minus the present value of all cash outflows (which equals the net present value) is greater than zero. Options with the highest NPV values are regarded as the most financially attractive options. The energy saving is the $ value of the recovered energy that would otherwise be produced from fossil fuels.

NPV formula: $$\sum_{t=0}^{N} \frac{\text{net cash flow in year t}}{(1 + \text{discount rate})^{\text{year t}}}$$

The preliminary economic assessments were based on the following assumptions:

- Discount (interest) rate: 10%
- Life time of technology: 15 years
- Fossil fuel costs: 5 A$/GJ (Office of Energy 2007b)
- Electricity price: 12 A$/MWh (Office of Energy 2007a)

Various approaches exist to undertake an economic assessment of a promising business opportunity, such as the Net Present Value approach discussed above and the simple payback period. Through discussions with the Kwinana industries, it was found that NPV is the most common approach used for the evaluation of energy efficiency and recovery options. Therefore, it was decided to use the NPV approach for the economic assessment of the flue gas recovery opportunities in order to maximise the industry uptake of opportunities.

8.2.8.3 Environmental Assessments

In line with the current debate on climate change and increasing awareness that emissions of greenhouse gases need to be controlled, the mitigation of carbon dioxide was estimated as part of the environmental assessment.

The options for energy recovery from Kwinana flue gases cover both thermal applications (e.g. heat exchangers, waste heat boilers) and electric applications (e.g. conventional combined cycle, Kalina and organic Rankine cycle). For the purpose of this study, it was assumed that the thermal applications substitute energy use in gas fired boilers. Therefore, the CO_2 mitigation from thermal applications was estimated from the avoided energy use that would otherwise be required to fire a natural gas boiler with an emission factor of 55 tonnes CO_2/TJ (AGO 2005b). The CO_2 mitigation potential for electric applications was estimated from the avoided energy consumption that would otherwise be required to generate the electricity in a conventional power plant from natural gas and coal sources. Electricity in Western Australia is generated from gas (about 60%) and coal (about 37%) (Riwoe et al. 2006). Therefore, the weighted average of the emission factors for a natural gas power plant (52.5 tonnes CO_2/TJ) and a coal fired power plant (93.8 tonnes CO_2/TJ) was applied (AGO 2005b).

8.2.9 Development and Implementation of Feasible Opportunities

The development of promising opportunities includes practical assistance to the Kwinana industries and the KIC with a strong emphasis on meeting their specific research needs to drive the opportunities forward. The work focuses on promising energy opportunities which have undergone a technical, economic, and environmental assessment (see previous subsection). Through discussions with the KIC and the industries, it became clear that a business case exists for bringing in external expertise to further develop promising energy recovery opportunities. The regional synergies research in the KIA is now facilitating the engagement between the Kwinana industries and external expert organisations to build upon the results of the flue gas methodology, and to assist with feasibility assessments of promising reuse opportunities (ongoing work). A promising area of research is an assessment of business and sustainability case for an evaporative water treatment / supply system utilising recovered energy from KIA flue gases.

8.3 Data Sources

The business case evaluation of the energy recovery opportunities identified in Kwinana was conducted according to the methodology detailed above. The estimated technical (efficiency), economic, and environmental data and their data sources are presented in Table 8.1. The underlying assumptions and formulas are included in Appendix 4.

The input data for the method application were derived from participating Kwinana industries (temperatures and flow rates of flue gases), literature (e.g. efficiency of waste heat boilers and economisers) and from empirical models (e.g. capital costs of heat exchangers). Informed estimates were made if no reliable datasets were available (e.g. for Kalina and organic Rankine cycles).

Data on the flue gas emissions were collected as part of an energy survey amongst the major energy consuming companies in Kwinana. Due to confidentiality reasons, individual company data can not be presented in this chapter.

The Kalina and organic Rankine cycles are emerging promising technologies which are expected to become more economically attractive in the near future. The lack of available data on the costs of these technologies influenced the recommendations regarding these technologies.

Overall, it is anticipated that the level of detail of the research presented is sufficient to provide guidance for engineering decision making by the Kwinana industries on which energy recovery opportunities to select for detailed feasibility assessments. It is acknowledged that actual costs are highly dependent on the resource characteristics (i.e. flow rates, temperature, composition flue gas, operating hours, regulatory requirements).

Table 8.1: Technical, Economic, and Environmental Source Data for Flue Gas Assessment

Technology Options	**Technical Data – Efficiencies**			**Economic Data[c] – Capital Cost**			**Environmental Data – Emission Factors**		
	Best-Case	**Worst-Case**	**Reference**	**Best-Case**	**Worst-Case**	**Reference**	**Best-Case**	**Worst-Case**	**Reference**
Energy Recovery	**[%]**			**[A$ / MW capacity]**			**[CO_2/TJ]**		
Heat exchanger	75[a]	65[a]	(Aquatemp Products Inc 1997)	$2845.6 * HTA^{-0.4506} * 1.35$		(Taal et al. 2003)	55		Estimated based on: (Winsconsin Department of Natural Resources n.d.)
Waste heat boiler	85[a]	70[a]	(Fath and Hashem 1987)	130,000	150,000	(Leith 2007)			
Economiser	85[a]	45[a]	(Farthing n.d.)	36,000	45,000	(Farthing n.d.)			
Kalina cycle	58[b]	47[b]	(Stambler 1992), (Icak et al. 2002), (Srinophakun et al. 2001), (Jonsson 2003), (Pilavachi 2000)	(-12.429 * inlet temp ^{o}C + 3208.6) * 1,220		(Valdimarsson and Eliasson 2003)	66		Estimated based on: (AGO 2005b) and (Riwoe et al. 2006)
Organic Rankine cycle	25[b]	20[b]	(Obernberger et al. 2002),(Drescher and Bruggermann 2007), (Canada et al. 2004)	(-15.886 * inlet temp ^{o}C + 3792.4) * 1,220		(Obernberger et al. 2002)			
Conventional combined cycle	50[b]	40[b]	(World Bank n.d.)	800,000	1,100,000	(World Bank n.d.)			
Energy Transportation	**[% loss / 100 metres]**			**[A$ / 100 metres]**			**[CO_2/TJ]**		
Insulated pipe	3	5	(US Department of Energy Efficiency and Renewable Energy 2002)	38,500	48,500	(Liegois 2003)	N/A		N/A

a) Thermal efficiency

b) Electric efficiency

c) Annual operational costs are estimated at 2.5% (best-case) to 5% (worst-case) of capital costs (World Bank n.d.; Obernberger et al. 2002)

8.4 Results from Application of Methodology

8.4.1 Preliminary Data

Figure 8.5 gives the total estimated energy consumption and energy releases of the Kwinana industries, as documented by the KIA energy survey. The major energy consuming industries in the KIA consume up to 80 PJ/yr in their processes. Gas is the most significant energy source in Kwinana (about 68% of total energy consumption), followed by coal (22%). Total energy release to the atmosphere is estimated at approximately 21 PJ/yr; this represents 27% of the total energy consumption. This indicates that there are significant opportunities for process energy recovery and other measures to reduce the energy releases to the atmosphere. Energy releases from flue gases are most significant in terms of energy content and temperature, compared with energy losses from hot water, hot air, steam, and hot products. The total energy release from the flue gases is estimated at approximately 6,000 TJ/yr, with up to 3,000 TJ/yr over 300^{o}C.

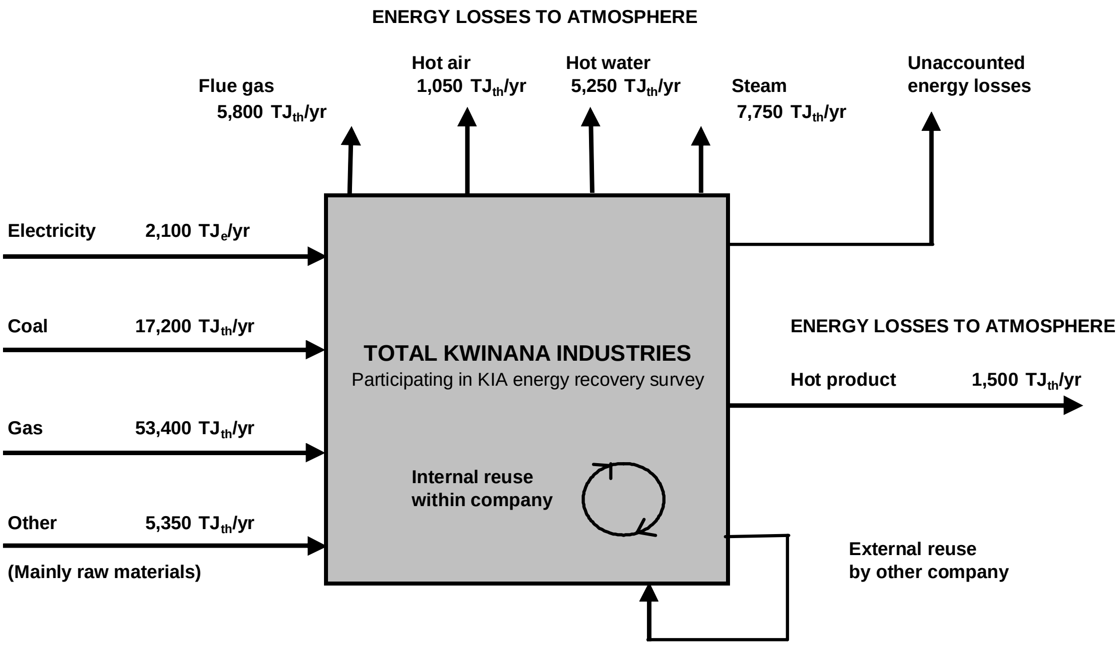

Figure 8.5: Energy Use and Release Diagram for the Kwinana Industrial Area

From the energy survey it became clear that the Kwinana industries have made significant progress in the past decade towards the improvement of energy efficiency, both at the company level (e.g. on-site energy assessments) and also through regional synergies (e.g. two cogeneration plants). These achievements provide a platform for further improvement of energy recovery in the region.

8.4.2 Identification of Opportunities

The decision was made at the opportunity identification workshop held (Van Beers 2006) to focus collaborative efforts on flue gases only, and not on other energy losses at this stage (e.g. steam, water, products). This was due to the limited recovery potential for these latter energy losses in terms of energy content and temperature. Following up on the workshop, a targeted methodology was developed to identify and evaluate the business case and sustainability benefits of energy recovery opportunities from flue gases (as described in the methodology section).

For the seven defined clusters in the KIA, a total of 55 collaborative (synergy) options were identified to recover energy from flue gases, involving a variety of technologies (e.g. heat exchangers, waste heat boilers, Kalina and organic Rankine cycles) and energy transportation through insulated pipes. In addition, the methodology identified numerous options for on-site energy recovery, such as heat exchangers pre-heating working liquids for on-site use and waste heat boilers. However, these are not further discussed here, as these are outside the scope of this thesis.

8.4.3 Evaluation of Opportunities

8.4.3.1 Cluster 4 as a Case-Study

Current Situation:

Using the methodology presented in this chapter, a techno-economic and environmental assessment of all identified energy recovery options was carried out. Cluster 4 (see Figure 8.2), which consists of a maximum number of options, was taken as a case study for the discussion of the results. A total of fifteen recovery options were identified for Cluster 4 including both thermal and electricity generating options. Table 8.2 presents the estimated energy savings, NPVs and CO_2 mitigation potentials for these options. Due the confidentiality reasons, company names have been removed from this table.

A centralised conventional combined cycle system producing electricity and thermal energy (option 15) fed by preheated working liquid from various industries has the highest energy recovery potential (avoided energy use between 1,600 and 2,700 TJ/yr). The recovered energy from this option (between 780 and 1,200 TJ/yr) accounts for approximately 35 to 50% of the total flue gas heat available in cluster 4 (2,400 TJ/yr). Heat exchangers in Company 1 and Company 2 (options 1 to 6) can recover 18 to 30% of the flue gas heat in Cluster 4 for thermal applications such as preheated working liquid (e.g. water). Although Kalina and organic Rankine cycle power plants (option 13 and 14) are centralised and receive heat from four different industries, the energy recovery potential from this option has been found to be only limited (at least compared to option 15). This is partly be explained by the estimated lower efficiencies for the two technologies (see Table 8.1) and subsequent uncertainties in these estimates.

The economic assessments of the fifteen options show that all well-established and proven technologies for thermal applications (e.g. heat exchangers and waste heat boilers) have positive Net Present Values and are therefore economically attractive. However, this is not the case for all electricity producing options. Firstly, these technologies are typically more complex and expensive (electricity generating unit) than equipment for converting energy for thermal applications. Secondly, the electricity generating options have to compete with low cost conventional electricity from the grid. Thirdly, in some cases energy must be transported over larger distances resulting in significant energy losses affecting economic viability.

Table 8.2: Technical, Economic, and Environmental Evaluation of Cluster 4

#	Collaborative Energy Recovery Options	Avoided Energy Use [TJ/yr]		Net Present Value [A$ 10^3]		CO_2 Mitigation [tonnes/yr]	
		Best-Case	Worst-Case	Best-Case	Worst-Case	Best-Case	Worst-Case
1	Company 1 supplying preheated working liquid to Company 2	615	445	22,700	15,800	33,900	24,400
2	Company 1 supplying steam to Company 2	430	175	13,500	2,700	23,700	9,600
3	Company 2 supplying preheated working liquid to Company 3	620	515	23,300	19,200	34,200	28,500
4	Company 2 supplying steam to Company 3	645	410	21,400	11,300	35,500	22,500
5	Company 2 supplying preheated working liquid to Company 4	490	345	17,800	12,100	26,800	18,900
6	Company 2 supplying steam to Company 4	475	155	14,600	1,100	26,200	8,500
7	Kalina cycle at Company 1 producing electricity and thermal energy, feeding from preheated working liquid from Company 2	1,420	1,070	-5,800	-8,200	93,900	71,000
8	Organic Rankine cycle at Company 1 producing electricity and thermal energy, feeding from preheated working liquid from Company 2	1,285	990	19,000	13,100	85,200	65,700
9	Conventional combined cycle at Company 1 producing electricity and thermal energy, feeding from preheated working liquid from Company 2	1,120	825	12,800	-3,000	74,000	54,600
10	Kalina cycle at Company 2 producing electricity and thermal energy, feeding from preheated working liquid from Company 4	900	720	-3,800	-5,700	59,700	47,700
11	Organic Rankine cycle at Company 2 producing electricity and thermal energy, feeding from preheated working liquid from Company 4	820	665	12,000	8,700	54,200	44,200
12	Conventional combined cycle at Company 2 producing electricity and thermal energy, feeding from preheated working liquid from Company 4	880	705	10,100	-1,100	58,400	46,600
13	Centralised Kalina cycle producing electricity only, feeding from preheated working liquid from Company 1, 2, 4, and 5	1,330	840	-36,900	-30,200	88,100	55,800
14	Centralised organic Rankine cycle producing electricity only, feeding from preheated working liquid from Company 1, 2, 4, and 5	575	360	-22,500	-18,300	38,000	23,700
15	Centralised conventional combined cycle producing electricity and thermal energy, feeding from preheated working liquid from Company 1, 2, 4, and 5	2,650	1,655	-6,400	-59,300	175,400	109,700

Evaluation of Future Scenarios:

It is recognised that the evaluation of the economic and technical feasibility of the recovery technologies is a dynamic issue. The feasibility of the identified recovery options is subject to numerous variables which may change in the near future. For example, it is almost certain that carbon taxes and/or other climate change policies will be implemented shortly in (Western) Australia (DITR 2006a; PMC 2007; Planet Ark 2007) . Due to increasing shortage and demand for gas, it is anticipated that the price for this energy source will increase significantly as well. In addition, Kalina and organic Rankine cycles are emerging technologies. The capital costs to install such technologies installed are expected to decrease significantly over the next decade through large scale production and application. To illustrate the effect of the above variables, three scenarios are being evaluated here:

- Scenario 1: no changes in electricity costs and gas price, implementation of carbon taxes of 5, 25, and 50 A$/tonne CO_2 respectively;
- Scenario 2: Carbon taxes plus electricity costs increased from 12 to 15 A$/MWh, and gas price increased from 5 to 10 A$/GJ;
- Scenario 3: Carbon taxes, increased energy prices (as above), plus capital costs of emerging technologies (Kalina and organic Rankine cycle) reduced by 50%.

It is acknowledged that these scenarios have been developed for the purpose of the comparative analysis. Additional scenarios can also be developed incorporating a range of different thermal and electric efficiencies, and decreasing capital costs of specific technologies. If desired, such alternative scenarios can be applied using the methodology presented in this chapter. The three scenarios listed above have been applied to the fifteen recovery options identified in cluster 4 (see Table 8.3).

Table 8.3: CO_2 Mitigation Potential through Economically Feasible Recovery Options – Evaluation of Scenarios – Cluster 4

#	Collaborative Energy Recovery Options	Technology[a]	CO_2 Mitigation [tonnes/yr]		Scenario 1[b]		Scenario 2[b]		Scenario 3[b]	
			Best-Case	Worst-Case	Best-Case	Worst-Case	Best-Case	Worst-Case	Best-Case	Worst-Case
1	Company 1 supplying preheated working liquid to Company 2	HEX	33,900	24,400	ü	ü	ü	ü	ü	ü
2	Company 1 supplying steam to Company 2	WHB	23,700	9,600	ü	ü	ü	ü	ü	ü
3	Company 2 supplying preheated working liquid to Company 3	HEX	34,200	28,500	ü	ü	ü	ü	ü	ü
4	Company 2 supplying steam to Company 3	WHB	35,500	22,500	ü	ü	ü	ü	ü	ü
5	Company 2 supplying preheated working liquid to Company 4	HEX	26,800	18,900	ü	ü	ü	ü	ü	ü
6	Company 2 supplying steam to Company 4	WHB	26,200	8,500	ü	ü	ü	ü	ü	ü
7	Kalina cycle at Company 1 producing electricity and thermal energy, feeding from preheated working liquid from Company 2	HEX + KC	93,900	71,000	~ (25)	~ (25)	ü	ü	ü	ü
8	Organic Rankine cycle at Company 1 producing electricity and thermal energy, feeding from preheated working liquid from Company 2	HEX + ORC	85,200	65,700	ü	ü	ü	ü	ü	ü
9	Conventional combined cycle at Company 1 producing electricity and thermal energy, feeding from preheated working liquid from Company 2	HEX + CCC	74,000	54,600	ü	~ (25)	ü	ü	ü	ü
10	Kalina cycle at Company 2 producing electricity and thermal energy, feeding from preheated working liquid from Company 4	HEX + KC	59,700	47,700	~ (25)	~ (25)	ü	ü	ü	ü
11	Organic Rankine cycle at Company 2 producing electricity and thermal energy, feeding from preheated working liquid from Company 4	HEX + ORC	54,200	44,200	ü	ü	ü	ü	ü	ü
12	Conventional combined cycle at Company 2 producing electricity and thermal energy, feeding from preheated working liquid from Company 4	HEX + CCC	58,400	46,600	ü	~ (5)	ü	ü	ü	ü
13	Centralised Kalina cycle producing electricity only, feeding from preheated working liquid from Company 1, 2, 4, and 5	HEX + KC	88,100	55,800	-	-	~ (50)	-	~ (25)	~ (25)
14	Centralised organic Rankine cycle producing electricity only, feeding from preheated working liquid from Company 1, 2, 4, and 5	HEX + ORC	38,000	23,700	-	-	-	-	~ (25)	~ (50)
15	Centralised conventional combined cycle producing electricity and thermal energy, feeding from preheated working liquid from Company 1, 2, 4, and 5	HEX + CCC	175,400	109,700	~ (25)	-	ü	-	ü	-

a) Technologies:
CCC = Conventional combined cycle
HEX = Heat exchanger
KC = Kalina cycle
ORC = Organic Rankine cycle
WHB = Waste heat boiler

b) Energy recovery option is:
Always viable = ‘ü’
Viability sensitive to carbon price = ‘~ (required carbon price is provided in brackets)
Never viable = ‘-‘ (option would require carbon price of over 50 A$/tonne)

Scenario 1 in Table 8.3 shows the effect of introducing carbon taxes on CO_2 mitigations through economically feasible recovery options. The options, which are feasible without a carbon price are well-established technologies for thermal applications (options 1 to 6). Among the power generation options, four options (8, 9, 11, 12) can economically mitigate CO_2 emissions from flue gases without carbon taxes (under best-case). The introduction of a low carbon tax (A$5 per tonne of CO_2) seems to have a limited effect on the economically feasibility of other power generation options (options 7, 10, 15); these need at least a carbon tax of A$25 per tonne of CO_2 to be viable.

Scenario 2 in Table 8.3 incorporates the effect of anticipated price increases for natural gas and electricity on the potential CO_2 mitigation through economically viable options. If prices of gas and conventional electricity increases and a carbon tax is introduced, most (except two) collaborative recovery options – which were identified – become feasible in best-case and worst-case scenarios. It must be noted that options 13 and 14 solely produce electricity and not any valuable thermal energy for reuse. This is because of the relatively low temperature of the flue gases (<300^{o}C) feeding into the Kalina and organic Rankine cycle plants for these two options.

The effect of the expected decrease in the capital costs of the Kalina and organic Rankine cycles is illustrated in Scenario 3 (combined with the carbon taxes and increased energy prices). As can be seen in the Scenario 3 column in Table 8.3, all options incorporating these emerging technologies become economically attractive for energy recovery from flue gases and thereby mitigate CO_2 emissions. A low carbon tax of A$5 per tonne of CO_2 does have a limited effect on the economically feasibility of the power generating options.

8.4.3.2 Best CO_2 Mitigation Options in Seven Clusters

It is useful to demonstrate to what extent the identified options in all seven clusters can mitigate CO_2 in an economically feasible way, including the effect of carbon taxes. For this purpose, the best CO_2 mitigation option in each cluster was selected and summarised in Table 8.4.

As can be seen in Table 8.4, an estimated 245 to 370 ktonnes of CO_2 can potentially be mitigated through energy recovery from flue gases in the KIA. This accounts for about 5% to 7% of the annual emission of 5 million tonnes of CO_2 from industrial processes in Western Australia (AGO 2005a). It is no surprise that the economic feasibility of all options increases with the introduction of the carbon taxes. In a worst case-scenario, the best CO_2 mitigation options for clusters 4 and 5 are not yet economically viable under current market conditions. It is expected that the reality is somewhere between these two scenarios, and therefore economically feasible with the introduction of carbon tax of 25 or 50A$ per tonne CO_2. The options that are economically attractive under current market conditions (cluster 1, 2, 3, 6, and 7) can mitigate approximately 136 ktonnes of CO_2, which accounts for approximately 35% of the total CO_2 mitigation potential in Kwinana. This implies that the remaining 65% (233 ktonnes of CO_2) can be economically mitigated through the introduction of carbon taxes.

Table 8.4: Evaluation of Best CO_2 Mitigation Options in Seven Clusters

Clusters	**Technology**[a]	**Application**[b]	**NPV for Different Rates of Carbon Taxes [A$ 10^3]**								**CO_2 Mitigation [tonnes/yr]**	
			Best-Case				**Worst-Case**				**Best-Case**	**Worst-Case**
			0 A$ / tonne	**5 A$ / tonne**	**25 A$ / tonne**	**50 A$ / tonne**	**0 A$ / tonne**	**5 A$ / tonne**	**25 A$ / tonne**	**50 A$ / tonne**		
Cluster 1	HEX	T	24,400	25,800	27,900	38,000	18,200	19,200	23,300	28,400	35,800	26,800
Cluster 2	HEX	T	41,500	43,900	53,100	64,700	31,500	33,200	40,300	49,200	60,900	46,600
Cluster 3	HEX	T	4,400	4,700	5,800	7,100	2,800	3,000	3,800	4,800	7,100	5,100
Cluster 4	HEX + CCC	E + T	-6,400	-20	26,900	60,300	-59,300	-55,200	-38,500	-17,600	175,400	109,700
Cluster 5	HEX + CCC	E + T	-1,900	283	9,100	20,100	-22,000	-20,600	-15,200	-8,500	58,000	35,500
Cluster 6	HEX	T	4,200	4,400	5,400	6,700	3,000	3,200	3,900	4,900	6,600	5,100
Cluster 7	HEX	T	16,800	17,800	21,600	26,400	11,700	12,400	15,100	18,600	25,200	18,100
										Total	369,000	246,900

a) CCC = Conventional combined cycle
HEX = Heat exchanger

b) T = Thermal
E = Electric

8.4.4 Key Findings

The key findings from the technical, economic, and environmental evaluation of the collaborative energy recovery opportunities from Kwinana flue gases are:

§ There exists significant potential to mitigate CO_2 emissions through energy recovery from Kwinana flue gases, by applying technologies to convert the embedded energy into useful thermal and electric applications.

§ It is acknowledged that on-site energy recovery and efficiency opportunities should be explored first, before going ahead with collaborative industry initiatives. The reason being that on-site options, generally, are not as much subject to the significant capital costs and energy losses associated with the transportation of waste energy from one company to another (energy losses and pipeline costs are significant, see Table 8.1). Significant energy losses occur when energy is transported over large distances (> 500 metres) between companies. Therefore it is of the utmost importance to keep the required transportation distances to a minimum. Distance is thus a critical factor in the economics of collaborative recovery options.

§ Most collaborative recovery opportunities to convert the flue gas energy into thermal applications (e.g. preheated working liquid) and combined electricity / thermal energy applications seem to be economically feasible under current market conditions. Options that solely produce electricity do not seem to be viable under current market conditions as these have to compete with low cost electricity from the grid.

§ The introduction of a low carbon tax (A$5 per tonne of CO_2) seems to have a limited effect on the economic viability of the power generation options. From the analysis in this chapter, it is clear that carbon taxes of A$25 to A$50 per tonne CO_2 are required to make a significant positive impact on the economic viability of energy recovery opportunities.

- The feasibility of the energy recovery options identified is subject to numerous variables which may change in the next few years. The assessment of possible scenarios shows that the anticipated decreasing capital costs of emerging technologies (such as the Kalina and organic Rankine cycles) and increasing energy prices will have a positive effect on the economic viability of energy recovery options which may currently not have a strong business case.

8.5 Conclusions from Application of Methodology

The aim of the methodology presented in this chapter was to arrive at potentially feasible energy recovery opportunities from Kwinana flue gases. The trial application of the methodology in Kwinana demonstrated its value in contributing to the identification of feasible collaborative energy recovery opportunities. The underlying assumptions and formulas related to the various technologies can be further improved if better quantitative data on these technologies become available. The methodology is not a stand-alone solution, rather should be used as a supplementary instrument to streamline the identification and evaluation of energy recovery opportunities and associated technologies. Although the methodology is specifically developed around energy losses from flue gases, it can be applied to other energy sources as well, such as hot water or steam (assumptions and formulas will need to be modified accordingly).

The research outcome is a set of on-site and collaborative recovery opportunities which have been subjected to preliminary technical, economic, and environmental assessments. The challenge for the future is to get one or more of the promising energy recovery opportunities implemented by the Kwinana industries. Follow-up work is undertaken to achieve this goal. This includes the involvement of external expert organisation(s) to assist with feasibility assessments of promising reuse opportunities, and ongoing consultation with the Kwinana industries and the Kwinana Industries Council to determine which recommended options have significant business and sustainability benefits and are achievable (e.g. potential business models and operational arrangements).

9 EVALUATION OF APPLIED METHODOLOGIES

9.1 Introduction

This chapter evaluates the trial application of the novel methodologies which have been developed to advance inorganic by-product, water, and energy synergies in the case-study area (the Kwinana Industrial Area).

The aim of the evaluation is to address the strengths and weaknesses of the customised methodologies in order to assess to what extent these fulfil the aim of this research and to suggest improvements for the developed and trialled methodologies.

The evaluation is conducted in four ways:

§ <u>Comparison against the cleaner production framework:</u> how did each customised methodology fit within the cleaner production framework and what were the main features in each phase, and how each customised methodology (e.g. inorganic by-product, water, energy) compare against each other;

§ <u>Multi-criteria evaluation:</u> what was the performance of the customised methodologies against a set of selected criteria, with the aim to assess the strengths and weaknesses of the developed methodologies and identify prospects to enhance these;

§ <u>Evaluation against requirements for regional synergy development:</u> which requirements need to be in place to apply the customised methodologies (or components thereof) effectively in industrial areas elsewhere in the world;

§ <u>Water-energy nexus:</u> perspectives on the relationships between identified water and energy utility synergies (e.g. water and energy requirements).

Each of the evaluation methods are discussed separately in the following sections. At the end of the chapter, conclusions are drawn from the results of the evaluation methods.

9.2 Comparison of Methodologies against Cleaner Production Framework

A comparison of the customised methodologies for inorganic by-products, water, energy against the cleaner production framework is provided in Table 9.1. The table shows how each customised methodology fits within the cleaner production framework and the main features in each phase. A brief discussion for each phase is presented below. A comparative review of the three customised methodologies (inorganic by-products, water, and energy) is provided thereafter.

Table 9.1: Comparison of Customised Methodologies against Cleaner Production Framework

Phase Cleaner Production Framework	Customised Components – By Theme		
	Inorganic By-Products	**Water**	**Energy**
Planning & organisation	§ Scoping workshop with industry and government § Scoping research tasks	§ Scoping workshop with industry § Scoping research tasks	§ Scoping workshop with industry § Scoping research tasks
Pre-assessment	§ Review of current practices and issues in KIA § Review of international experiences § Identification and evaluation of promising synergy opportunities § Prioritisation of synergy opportunities based on available volume of reusable by-products., potential business and sustainability case, work undertaken previously	§ Assessment of industry water input and output flows § Identification of synergy opportunities § Preliminary evaluation and prioritisation of synergy opportunities § Prioritisation of synergy opportunities based on water quality match, quantity / distance ratio, and potential to be icon project for the region (volumes and benefits)	§ Assessment of industry energy input and output flows § Preliminary evaluation of industry energy releases § Selection of flue gas energy as priority area § Prioritisation of synergy opportunities based on temperature and heat content of energy releases
Assessment	§ Producers base: assessment of inorganic by-products available in the KIA § Customer base: market assessment § License to operate: engagement with government § Technology base: focus on low-cost technologies	§ Opportunity screening workshop with industry § Selection of promising synergy opportunities § Split between one-on-one industry and collaborative (more than two industries) synergy opportunities	§ Selection of appropriate energy recovery technologies § Detailed scoping study into energy recovery from KIA flue gases § Split between on-site and collaborative reuse opportunities § Assessment of the effect of carbon taxes on viability of reuse options
Feasibility studies	§ Focus is on development of reuse guidelines for selected reuse applications	§ Industry assistance to feasibility assessments of selected one-on-one synergies	§ Involvement of external expert organisation(s) to assist with feasibility assessments of promising reuse opportunities

Phase Cleaner Production Framework	Customised Components – By Theme		
	Inorganic By-Products	**Water**	**Energy**
Implementation & continuation	§ Focus is on implementation of reuse guidelines and lifecycle sustainability assessments § It is anticipated that implementation of inorganic by-product synergies will result from development of regulatory reuse standards and protocols	§ One water synergy being implemented so far § It is anticipated that more synergies will be implemented after completion of feasibility assessments § Increasing industry interest in the production of fit-for-purpose water from municipal secondary treated effluent, possibly with the utilisation of industry waste heat	§ It is anticipated that promising reuse opportunities will be implemented after completion of detailed feasibility assessments and involvement of external expert organisations. § Rapidly evolving GHG regulations will encourage uptake of identified reuse options
	§ The research on regional synergy development in Kwinana is continuing as part of the CSRP Kwinana Synergies Project (see Section 1.3), building upon and utilising outcomes of the research presented in this Thesis.		

9.2.1 Review of Methodology Phases

Planning and organisation phase: The structure and application of the planning and organisation phase was consistent amongst the three methodologies. For all three methodologies, it included scoping workshops with the industries, scoping the research tasks to be conducted as part of the subsequent phases ("who does what when"), and securing industry commitment on the way forward.

Preliminary assessment phase: For all three methodologies, preliminary industry data (specific to the three themes) were collected, followed by the initial identification and screening / prioritisation of synergy opportunities. A detailed review of international practices (mainly related to regulatory frameworks and reuse standards) was conducted for the inorganic by-products methodology, because regulation is one of the main barriers preventing the reuse of these by-products on a large scale and routine basis. This exercise was not required for the other two methodologies since regulations are not such a strong barrier to establishing water and energy utility synergies. The prioritisation of the synergy opportunities are based on elements of specific relevance to the resource under investigation (inorganic by-products, water, energy) and to allow (pragmatic) decision making on which synergy opportunities to take forward for more detailed assessments. It is not claimed that the prioritisation processes lead to the identification of synergies which result in 'sustainable resource processing', but rather identify those opportunities which have a potential business case to contribute to sustainable resource processing by reducing waste and emissions and increasing resource efficiencies.

Assessment phase: Industry had significant input in the selection of promising synergy opportunities (through the opportunity screening workshops) as part of the customised methodologies for water and energy. The selection process for inorganic by-products reuses depended more on external factors, such as regulations and market demand. All water and energy synergies identified occur within the KIA since it is not viable to transport energy and water over larger distances. Therefore, a clear distinction between on-site (eco-efficiency) and collaborative (synergy) opportunities was made in the energy methodology. The same could be argued for water. However, through discussions with the Kwinana industries, it became clear that the industry research needs were centred around the identification and development of water synergies, rather than on-site water efficiency assessments. Most Kwinana industries have undertaken detailed on-site water efficiency assessment over the past decade. Therefore, it was decided to focus the water methodology solely on synergy opportunities, and not on on-site water efficiencies measures. As part of the assessment phase for energy, the impact of emerging climate change policies (e.g. carbon taxes) was evaluated. This was not the case for the other two methods. However, as part of the inorganic by-product methodology, a process seeking to establish regulatory reuse standards and protocols has been initiated to support the reuse of inorganic by-products on a significant scale and on a routine basis.

Feasibility phase: Through the methodology on water and energy, assistance to the industries with the feasibility studies was provided based on the specific research needs of the industries involved. The difference is that for the energy method, external expertise is being brought in to further develop promising energy recovery opportunities with the Kwinana industries. The focus of the feasibility phase of the inorganic by-product methodology is on the initiation and development of reuse guidelines rather than actual feasibility studies for specific reuse opportunities. It is anticipated that the implementation of inorganic by-product reuses will happen after the reuse guidelines have been put into place.

<u>Implementation and continuation phase:</u> One of the challenges for the research is to facilitate the implementation of promising synergy opportunities. Strong commitment from the industries and the Kwinana Industries Council has assisted in achieving this goal (and will continue to do so). An example of a synergy which is being implemented by the industries is the treatment of oily wastewater from the Kwinana Nickel Refinery by the BP Refinery. An example of a future synergy with promising prospects for implementation is the supply of treated effluent from CSBP Chemical Plant to the Kwinana Nickel Refinery (about five years away). It is anticipated that more synergies will be implemented after completion of feasibility assessments (ongoing work). For the inorganic methodology, the implementation of inorganic by-product synergies will likely follow from initiation and development of regulatory reuse standards. The regional synergy development research in the KIA is continuing, building upon the methodologies and outcomes presented in this thesis. For the three themes (inorganic by-products, water, energy), focus areas for future research have been identified which will contribute further to the sustainability of the KIA. An example is the development of regulatory reuse standards for inorganic by-products. Furthermore, a scoping study into an evaporative water treatment/supply system (utilising recovered energy from industry flue gases) is being initiated with support from the Kwinana Industries Council and its members.

9.2.2 Differences in Customised Methodologies

Building upon Table 9.1, a summary of the differences in the three customised methodologies (inorganic by-products, water, and energy), and their underlying reasons is summarised below.

A strong focus of the inorganic by-product methodology is on international experiences related to the reuse of these by-products and establishing a collaborative approach to assist with the initiation of regulatory reuse standards in WA. In contrast, the water and energy methodologies have a strong(er) technical focus. The underlying reason being that each methodology was developed to tackle the main issues limiting the uptake of inorganic by-product, water, and energy synergies. Inorganic by-product reuses in Kwinana are limited by the absence of regulatory reuse standards to enable their large scale application on a routine basis. While for the water and energy methodologies, the limiting factors included a lack of industry awareness on the quantities and qualities of alternative water sources (e.g. treated effluents, cooling water, flue gases) available for reuse by other industries and a preliminary assessment of the business and sustainability case for reusing of these resources.

The level of external stakeholder engagement is most significant for the inorganic by-product methodology. As outlined in Chapter 6, a key component of the methodology for inorganic by-product is the initiation of a collaborative stakeholder approach in order to secure government and community for inorganic by-product reuse with a sound business and sustainability case. On the other hand, community and government issues related to the water and energy utility synergies are limited, and therefore their required involvement was limited. For water and energy utility synergies it is more a matter of building an economic and technical business case for the industries involved. Overall, there is government and community support for industrial water and energy reuses within and by industries. It may become a different matter if the water and energy synergies would specifically apply to a domestic application (e.g. the treatment and subsequent reuse of industrial and domestic effluents to potable water standards). However, this was not the case for the customised methodologies for water and energy synergies developed as part of this PhD research.

The feasibility assessment phase for the energy methodology included the involvement of external expert organisations to assist with the feasibility assessments of promising reuse opportunities. This was not the case for the inorganic by-product and water methodologies. For the water methodology, the detailed feasibility studies were conducted by the industries themselves. It is noted that this is subject to the expertise available within the industries involved and the technical difficulty of the selected synergy option(s). It may well be the case, if other water synergy opportunities were taken forward for detailed assessments or if the methodology was applied in other case-study areas, that the feasibility studies would benefit from external expert or engineering organisations as well. The focus of the feasibility assessment phase for inorganic by-products is on the initiation and development of regulatory reuse guidelines. It is anticipated that the implementation of inorganic by-products will result from the development of these guidelines. Overall, the feasibility phase for each methodology has been customised based on the specific opportunities identified and the specific research needs of the industries.

9.3 Regional Synergies versus On-Site Efficiencies

9.3.1 Prioritisation

Regional synergy projects must compete with other innovation projects within the companies that could offer a higher economic return on investment, including on-site efficiency gains or required plant modifications. The Kwinana industries, in general, take a range of criteria into consideration when deciding on an investment. As expected, this includes an assessment of the economics (Net Present Value is most commonly used), but extends to criteria such as strategic importance to the company and the ongoing and future license to operate of the company. For strategic reasons, a company may decide to engage in a synergy opportunity with a lower economic return if the project can guarantee the long-term supply of a resource (e.g. water) critical to the company core business. The Kwinana Water Reclamation Plant is a good example in this case (see Section 4.2.4). There is currently a lack of available tools and methodologies to evaluate the broader sustainability benefits of synergy opportunities in a constructive and consistent manner, also in relation to on-site efficiency options; this research topic is outside the scope of this PhD research. A novel methodology to evaluate the full triple-bottom-line impacts of a synergy opportunity is being developed through a separate PhD research project (Kurup et al. 2005).

One could argue that it is a valuable exercise to locate the regional synergy opportunities identified within a cost-effectiveness framework (e.g. Turner et al. 2008 or Enkvist et al. 2007). As outlined earlier in this thesis (Section 4.6), each synergy is unique in terms of its business case, strategic issues, drivers, barriers, and sustainability benefits. Therefore, the author perceives limited value in plotting how the synergy opportunities rank against other initiatives that the company could be doing. Such an exercise would suffer from lack of available data and business response as some of these elements will be commercially sensitive and/or confidential. Furthermore, the exercise would not justify the wide range of uncertainties and external factors affecting the options.

Overall, the hierarchy of waste management priorities (in order of preference: avoidance, reduction, segregation, reuse, recycling, treatment, and disposal) should be considered when deciding on the development and implementation of opportunities to increase resource efficiencies and manage the waste and emissions in the case-study area (and elsewhere). The main focus of the cleaner production approach is on the avoidance, reduction of wastes and emissions, while industrial ecology tends to focus on the reuse, recycling, treatment of resources. Therefore, preference should be given first to on-site (cleaner production) opportunities before applying industrial ecology or regional synergies. Although these issues have been reviewed as part of this research, it is acknowledged that the assessment of cleaner production versus regional synergy opportunities has not been not formalised as such in the customised methodologies presented in this thesis. As a result, this element has been added to the recommendations for the methodology improvement (see Section 10.5).

9.3.2 Vulnerability

It is recognised that some of the synergy opportunities identified in this research may become unviable if, for example, a company implements a significant on-site efficiency, reduces production, or a respective resource declines (e.g. fresh water). Furthermore, the dynamic nature of industry developments in the case study 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 elsewhere. 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 establishment of the pig iron making plant (See Section 4.2.4).

The author notes that these uncertainties should be regarded as normal business practices and the same can be argued, to a certain extent at least, about cleaner production opportunities. For example, on-site efficiency gains in heavy industries are often made through technology upgrades or modification of its operations. These capital intensive projects mean that eco-efficiencies are locked in for the economic life of the upgrade/modification.

In this PhD research, the regional synergy concept is regarded as one of the avenues to progress towards more sustainable resource processing, mainly through increasing resource efficiencies and reducing wastes and emissions. If a synergy project ceases to exist because it has become unviable due to reasons outlined above, the respective resource (e.g. inorganic by-product, water or energy flow) will be available "on the market" again. This means that the producing company will actively seek feasible on-site (cleaner production) or regional synergy alternatives for the resource. As an interim solution, the company may decide to temporarily dispose and landfill the resource until a viable reuse has been found. This obviously has a negative effect on the overall sustainability of an industrial region.

There is limited potential for incorporating or minimising these business uncertainties in the customised methodologies developed as part of the PhD research, or in fact any other methodology with a focus on business improvements. However, the cleaner production concept and its application framework (Figure 2.1) are based on a continuous improvement process. The same applies to the customised methodologies for enhancing inorganic by-product, water, and energy synergies. These provide overarching and flexible frameworks to (continuously) identify and evaluate synergy opportunities in an industrial area, also for reuse projects that have ceased because of a changing business environment.

9.4 Multi-Criteria Evaluation

A multi-criteria evaluation was undertaken to review the performance of the customised methodologies against a set of selected criteria, with the aim to assess the strengths and weaknesses of the developed methodologies and identify prospects to enhance these.

9.4.1 Evaluation Methodology

The multi-criteria evaluation described and applied in this section is based on Van Beers (2000). Values were assigned based on the author's extensive practical experience in the application of the methodologies for advancing inorganic by-product, water, and energy synergies in the case-study area. Furthermore, the author has experience with applying the multi-criteria evaluation method elsewhere (with small and medium sized enterprises in Cape Town, see Van Beers 2000).

The customised methodologies for advancing inorganic by-products, water, and energy synergies were evaluated on the following seven criteria (key statements regarding the underlying reason for the criteria selection are provided in brackets):

- <u>'Effectiveness'</u> concerns the quality or usefulness of the achieved results from the applied methodology with respect to increasing resource efficiencies and reduce waste and emissions (time and financial investments must result in beneficial outcomes for the stakeholder involved);
- <u>'Added value to stakeholders'</u> are the experienced benefits resulting from the applied methodology for each stakeholder group (if there are no direct or indirect benefits for the stakeholders (e.g. industries, government, community) it is unlikely that their interest and participation can be acquired and maintained);
- <u>'Time-investment'</u> assesses the experienced time-investments to apply the methodology successfully ('time is money');
- <u>'Efficiency'</u> is determined as the ratio between the time-investment and the quality of results (for a methodology to be successful it must lead to

successful outcomes with least possible amounts of efforts and time investments);

- ‘Required skill level’ assesses the expertise or knowledge needed to successfully complete the methodology application (if the methodologies are to be applied elsewhere, one needs to know what skill set is required to undertake this successfully);
- ‘Stakeholder participation’ assesses the quantity (number) and quality (willingness to co-operate) of involved industries and other stakeholders during the methodology application (where required, the methodology must involve appropriate stakeholders to drive forward the regional synergy initiatives);
- ‘Complexity’ is defined as the time and effort required for the involved stakeholders to fully understand the purpose, structure and functioning of the methodology (stakeholders must be able to comprehend the methodology in order to support or provide input into the synergy development process); and
- ‘Systematic approach’ examines to what extent the results of the methodology application were achieved in a structured and systematic manner (in this thesis, the cleaner production framework is used as an overarching platform for customised methodologies to facilitate the development of inorganic, water, and energy synergies).

Each evaluation criteria was rated according to one of five categories summarised in Table 9.2.

Table 9.2: Rating for Multi-Criteria Evaluation

Rating	Explanation
Significant strength (+ +)	Assigned if an evaluation criteria has a considerable positive impact on the conducted experiments and its results, without having any negative features which decreased the value of the experimental work and/or reduced the quality of the results
Moderate strength (+)	Allocated to an evaluation criteria which has an overall positive impact on the conducted experiments and its results, but also has certain negative features which decreased the value of the experimental work and/or reduced the quality of the results
Neutral/indeterminate (O)	Assigned if an evaluation criteria has both positive and negative features regarding the experimental work and its results, or if the rating of an evaluation criteria cannot be determined

Rating	Explanation
Moderate weakness (Score -)	Means that an evaluation criteria has an overall negative impact on the conducted experiments and its results, but also has a number of positive features which increased the value of the experimental works and/or improved the quality of the results
Significant weakness (Score - -)	allocated to an evaluation criteria which has a considerable negative impact on the conducted experiments and its results, without having any positives features which increased the value of the experiments and/or improved the quality of the results

9.4.2 Evaluation of Methodology to Advance Inorganic By-Product Synergies

The results from the multi-criteria evaluation of the inorganic by-product methodology are presented in Table 9.3. From the table it is clear that effectiveness, added value to stakeholders, and stakeholder participation are key strengths of the methodology applied within the KIA. These strengths relate to the development of regulatory standards which will enable the reuse of high volumes of inorganic by-products. At present, these standards do not exist; the reuse standards and guidelines are still being initiated and developed. The collaborative development of methodology - with the industries, government, Kwinana Industries Council, and community is ongoing. The development of these reuse standards will take time to ensure sustainable outcomes for all parties involved. The weaknesses of the collaborative methods concern the significant time investment and relative complexity. The required skill level and systemic approach are rated as a moderate weakness and strength respectively.

Table 9.3: Evaluation of Methodology to Advance Inorganic By-Product Synergies

Criteria		Comments	Rating
1	Effectiveness	Main outcome of the collaborative methodology will be regulatory guidelines for the reuse of inorganic by-products. These will facilitate the implementation of reuse projects by industry. Without these guidelines it is unlikely that reuse of inorganic by-products will occur on a significant scale.	+ +
2	Added value to stakeholders	The eventual implementation of large volume reuses of inorganic by-products (as a result of the collaborative method) will provide range of sustainability benefits.	+ +
3	Time investment	Stakeholder engagement is a time consuming process, including the initiation and development of regulatory guidelines.	- -
4	Required skill level	Due to the comprehensive nature of the collaborative methodology, a wide range skill set is required to execute the methodology.	-

Criteria		Comments	Rating
5	Stakeholder participation	Collaborative methodology has support from wide range of stakeholders (e.g. Kwinana Industries Council, Kwinana industries, local and state government, and research providers).	+ +
6	Complexity	The collaborative method is designed to overcome a set of barriers associated with the reuse inorganic by-products. Many issues affect the stakeholder engagement process. The development of regulatory reuse guidelines is a complex process.	- -
7	Systematic approach	Each component of the collaborative methodology is carried out and addressed in a structured manner.	+

9.4.3 Evaluation of Methodology to Advance Water Utility Synergies

Table 9.4 shows the multi-criteria evaluation of the methodology developed to advance water utility synergies in the case-study area. The overall effectiveness is rated as a moderate strength because the application of the methodology resulted in a set of promising synergy opportunities which are being considered for implementation by the Kwinana industries. A synergy that is being implemented so far is the treatment of oily wastewater from the nickel refinery by the nearby oil refinery. The effectiveness of the methodology is constrained to a certain extent by the fact that regional synergy development is not industry core business. In addition, synergy projects must compete with other innovation projects that could offer a higher economic return on investment. This issue can be addressed by conducting a full triple-bottom-line assessment for a synergy opportunity, rather than encouraging industries only reviewing the economic benefits. The development of such triple-bottom-line methodology is outside the scope of this thesis, but is addressed by a separate PhD research project (Kurup et al. 2005). Added value to stakeholders, stakeholder participation, and a high level of systematic approach are significant strengths of the methodology. These strengths should be capitalised upon when applying the methodology in other industrial regions. Required skill level is considered as a moderate strength, because “only” a basic understanding of water treatment technologies is required to apply the methodology. The methodology provided a transparent and flexible process for the identification and preliminary evaluation of water synergy opportunities, therefore the level of complexity is rated as a moderate strength. The time investment to apply the methodology is considered to be neutral because the collection of qualitative and quantitative water data from the industries was a time consuming process. However, the identification and preliminary evaluation of synergy opportunities could be done in a relative short timeframe. The feasibility studies of selected water synergies are conducted over a longer time period (depending on the business priorities of the industries involved).

Table 9.4: Evaluation of Methodology to Advance Water Utility Synergies

Criteria		Comments	Rating
1	Effectiveness	The methodology application resulted in a set of promising one-on-one company synergies which are being considered for implementation by the industries (one synergy implemented so far). Feasibility studies for selected collaborative synergies (involving more than two companies) are being conducted.	+
2	Added value to stakeholders	Water security is key issue for the KIA and the industries. The methodology provided a comprehensive set of synergy opportunities for consideration by the industries. These assist with improving water efficiency and securing water resources for the future.	+ +
3	Time investment	Collection of qualitative and quantitative water data from the industries was a time consuming process. Identification and preliminary evaluation of synergy opportunities could be done in a relative short timeframe. The feasibility studies of selected water synergies are conducted over a longer time period (depending on priorities of the industries involved).	0
4	Required skill level	Basic understanding of water treatment technologies and industry engagement skills are required to apply the methodology.	+
5	Stakeholder participation	Significant industry interest and participation throughout the methodology application, including scoping and opportunity screening workshops and one-on-one industry interactions.	+ +
6	Complexity	Methodology provided a transparent and flexible process for the identification and preliminary evaluation of water synergy opportunities (e.g. through water synergy source/sink diagrams).	+
7	Systematic approach	Each step of the methodology was clearly defined and followed up on results from previous steps. It was a typical narrow-down approach, e.g. start broadly with synergy identification and then focus on promising opportunities.	+ +

9.4.4 Evaluation of Methodology to Advance Energy Utility Synergies

The results from the multi-criteria evaluation of the methodology to advance energy utility synergies are presented in Table 9.5. A comprehensive set of on-site and collaborative energy recovery opportunities from industry flue gases was identified and assessed as part of the methodology application. A selection of promising energy recovery options is being investigated in detail by expert organisations and the industries. In addition, the results from the methodology application are leading to a detailed scoping study into an evaporative water supply system in the KIA, utilising the energy from the industry flue gases. Therefore, the effectiveness and added value to stakeholders of the methodology are considered to be a significant strength. The highly systematic approach is a key strength as each step of the methodology was clearly defined and followed up on results from previous steps. It was a typical narrow-down approach, e.g. start broadly with identifying priority areas, followed by synergy identification, and then assessing promising opportunities. There was industry participation throughout the methodology application. There is an increasing industry interest in the results from the methodology application due to changing business drivers (e.g. increased energy prices, GHG policies). As a result, stakeholder participation is considered to be a moderate strength. Collection of energy data from the industries was a time consuming process, and so was the development of the methodology. However, with the methodology framework completed, the identification and preliminary evaluation of the energy recovery opportunities could be done in a relative short timeframe. The feasibility studies of selected energy recovery opportunities are still in progress. Overall, the time investment to apply the methodology is considered to be a moderate weakness. Required skill level and level of complexity are rated as neutral.

Table 9.5: Evaluation of Methodology to Advance Energy Utility Synergies

Criteria		Comments	Rating
1	Effectiveness	A comprehensive set of on-site and collaborative energy recovery opportunities from industry flue gases were identified and assessed as part of the methodology application. A set of promising energy recovery options is being investigated in detail by selected expert organisations and the industries. In addition, results from the methodology application led to a detailed feasibility study into an evaporative water supply system in the KIA, utilising the energy from the industry flue gases (work in progress).	+ +
2	Added value to stakeholders	The opportunities identified assist industry with improving their energy efficiency and reducing GHG emissions. Business drivers for energy efficiency and recovery are changing rapidly (e.g. increased energy prices, GHG policies). The anticipated introduction of carbon taxes will have a positive effect on the economic viability of the options identified.	+ +
3	Time investment	Collection of qualitative and quantitative energy data from the industries was a time consuming process, and so was the development of the methodology (e.g. cost proxy indicators, efficiency of various energy recovery technologies). With the methodology framework completed, the identification and	-

Criteria		Comments	Rating
		preliminary evaluation of the energy recovery opportunities could be done in a shorter timeframe. The feasibility studies of selected energy recovery opportunities are still in progress.	
4	Required skill level	Basic understanding of energy recovery technologies and industry engagement skills are required to apply the methodology.	0
5	Stakeholder participation	There was industry participation throughout the methodology application, including scoping and opportunity screening workshop and one-on-one industry interactions. There is an increasing industry interest in the results from the methodology application due to changing business drivers.	+
6	Complexity	Methodology provided a transparent and flexible process for the identification and evaluation of energy recovery opportunities (e.g. on-site versus collaborative opportunities, industry clustering, economic/technical/environmental assessments).	0
7	Systematic approach	Each step of the methodology was clearly defined and followed up on results from previous steps. It was a typical narrow-down approach, e.g. start broadly with identifying priority areas, followed by synergy identification, and then assess promising opportunities.	+ +

9.5 Requirements for Methodology Application Elsewhere

The aim of this evaluation is to determine the suitability of the customised methodologies (based on the cleaner production framework) for regional synergy development in industrial areas elsewhere in the world. Based on the experiences in Kwinana as a case-study area and a rating system (Table 9.6), an assessment of the requirements to apply the methodologies successfully elsewhere is provided in Table 9.7. The evaluation is performed on each phase of the cleaner production framework. The requirements and their ratings are discussed in detail in the following subsections. It is noted that further research will be required to validate and quantify these requirements.

Table 9.6: Rating of Requirements for Methodology Application Elsewhere

Rating	Explanation
O	Not essential
l	Recommended, but not essential
l l	Highly critical, strongly recommended

Table 9.7: Requirements for Methodologies Application Elsewhere

Requirement	Effected Phases of Cleaner Production Framework: Planning & Organisation	Pre-Assessment	Assessment	Feasibility Studies	Implementation & Continuation	Theme / Methodology
Distances between industries	O	O	O	O	O	Inorganic by-products
	I	I	I	I	I	Water
	I I	I I	I I	I I	I I	Energy
Number and diversity of industries	O	I I	I I	I	I	Inorganic by-products
						Water
						Energy
Industry interest and industry champions	I I	I I	I I	I I	I I	Inorganic by-products
						Water
						Energy
Industry organisation	I I	I I	I	O	O	Inorganic by-products
						Water
						Energy
Regulations	O	I	I I	I I	I I	Inorganic by-products
	O	O	O	O	O	Water
						Energy
Community support	I	I	I I	I I	I I	Inorganic by-products
	O	O	O	O	O	Water
						Energy
Know-how and expertise	O	I I	I I	I I	I	Inorganic by-products
						Water
						Energy
Access to funding	O	I I	I I	I I	I	Inorganic by-products
						Water
						Energy
Corporate culture	I	I I	I I	I I	I I	Inorganic by-products
						Water
						Energy

9.5.1 Distances between Industries

Distances between industries pose a challenge with regard to the recovery and reuse of by-products, water, and energy. With regard to transportation issues and costs, a distinction must be made between synergies where the resource (by-product, water, energy) is reused by another industry in the same industrial area or where reused in more dispersed applications outside the region (such as road construction or agricultural products). The challenge is to keep the required transportation distances to a minimum. It does not make good business sense to consider reuse options where low-value resources need to be transported over large distances (>50 or 100 kilometres).

Before applying the customised methodologies in a given industrial area, careful consideration should be given first to the location and distances between the companies in the region. Distance is the most critical for the development of energy utility synergies because of the significant energy losses that occur during energy transportation (3 to 5% per 100 metres, see Table 8.1).

N.B.: Transportation costs can also be a driver for regional synergy development. For example, transportation typically accounts for up to one third of the production costs of cement and concrete aggregate in Western Australia (Van Beers et al. 2006). This is because “virgin” raw materials have to be transported from outside the Perth Metropolitan Area. Therefore, transportation costs are reduced significantly if resources mined far away are substituted with by-products available in industrial areas close(r) to the user markets.

9.5.2 Number and Diversity of Industries

The diverse blend of key processing and manufacturing industries primarily producing for international markets with limited local competition between companies are contributing factors that have turned the KIA into a world class example of regional synergy development. The existing synergies provide environmental benefits to the community beyond what could be achieved by widely dispersed industries. The non-competitive environment contributes to open communications between the industries in the region which benefits regional synergy development. Having a diversity of industry sectors in an industrial area results in a wide variety of resource input and output flows available for inter-industry exchanges.

The application of the customised methodologies for inorganic by-products, water and energy synergy development is likely to identify a higher number of synergy opportunities in industrial areas where there is a large number of diverse (non-competing) industries. The validation and quantification of this requirement is outside the scope of this research. Further research will be required to address this issue.

It must be noted, however, that synergy development could still be successful in industrial areas where there are only a small number of industries operating in the same industry sector. An illustrative example is the Gladstone Industrial Area (Queensland, Australia) which compares favourably with renowned international examples in terms of the current level and maturity of existing regional synergies in the area. Gladstone is remarkable as it stands out with regard to unusually large geographic boundaries and the high dominance of one industry sector (Van Beers et al. 2007b).

9.5.3 Industry Interest and Industry Champions

The core focus of industry personnel is to devote their day-to-day efforts to core business activities rather than on the development of regional synergies (unless there is an overwhelming commercial benefit). One of the aims of the customised methodologies is to provide practical support to industries with the identification and development of promising synergy opportunities; an activity that is not regarded as company core business.

There must be a genuine interest and commitment from the industries in the region to work with the facilitating body (e.g. researchers, industry organisation, or consultancy firm) throughout the synergy development process (from the planning and organisation of the project to the implementation of feasible synergies). This includes discussions in workshops, providing industry data, reviewing project results, and consideration of recommended synergy opportunities.

Industry champions are people within the companies who can envisage the potential business and sustainability benefits that regional synergies can provide to their company and the region as a whole, and support the initiative to identify and develop promising synergies. These industry champions are crucial for the synergy development process and can encourage other industry partners to participate in the project. Industry champions are often environmental or sustainability managers of the larger companies that have a proven track-record and pro-active attitude towards sustainability issues. The identification of industry champions was not formulised in the development of the customised methodologies for the Kwinana case-study. However, if the methodologies are to be applied elsewhere, it is recommended to incorporate this element in the early phases of the project (e.g. planning and organisation phase).

If there is an initial industry interest in the development of regional synergies in a given industrial area, the interest is generally maintained by providing practical assistance that meets the specific research needs of the companies involved. The methodologies presented in this thesis have been developed to meet the specific needs of the stakeholders involved (i.e. industries, government) in the case-study area. If the methodologies are to be applied elsewhere, the methodologies will need to be modified based on the local research needs, conditions (e.g. regulations), and type and number of industries located in the industrial area under investigation.

9.5.4 Industry Organisation

An industry organisation (or a similar networking body) establishes lines of communication between companies in the region that may otherwise not have any direct or obvious business reason to communicate. An industry organisation operating in a region can significantly advance the development of opportunities for industries to work together for the common good of the industrial area. An industry organisation (like the Kwinana Industries Council, see Section 2.8.2) engenders a great level of cooperation and trust between the operations and consequently helps smooth the way for the development of joint initiatives. The importance of building relationships between representatives of the companies in the region should not be underestimated and is an essential component of the development of synergies. A successful regional synergies project needs to have a powerful focusing to capture the attention of people from a range of different industries across a region.

The industry organisation is most critical in the initial stages of the customised methodologies; i.e. the planning/organisation and pre-assessment phases of the project. In the planning and organisation stage the industry organisation provides the platform for industry discussions on the scope, priorities, kick-off of the project. In the pre-assessment phase the industry organisation can facilitate the opportunity focused workshops and encourage the companies to provide the initial baseline industry data required. Throughout the subsequent stages of the project (assessment, feasibility studies, and implementation and continuation), the industry organisation plays an important role in the overall guidance of the project and addressing emerging project issues collectively.

9.5.5 Regulations

Regulations can be both a driver and barrier for regional synergy development, as illustrated in previous sections of this thesis (Section 4.4.5, Section 4.5.3, and Section 6.3.3), and examples below.

In the case of the KIA, government support for the widespread implementation of regional synergies is not yet forthcoming. There is a (mis)perception that by-products are by definition wastes (and therefore contaminated), rather than valuable alternative raw materials with similar characteristics as traditional resources. The current regulatory framework in WA supports the established raw materials industries, rather than to enable the reuse of available (inorganic) by-products in different industry sectors on a large scale and routine basis.

On the other hand for example, business drivers for energy conservation are changing rapidly in Australia, through for example the introduction of mandatory energy opportunity assessments (and their public disclosure) for large users (> 0.5 PJ/yr), climate change policies, and potentially a carbon trading system. It is anticipated that these regulatory developments will result in improved energy efficiency and enhanced energy recovery at Kwinana operations, possibly through energy utility synergies.

It is recommended that the existing regulatory frameworks be carefully reviewed, before application of the customised methodologies (particularly for inorganic by-products) in other industrial regions. This is less critical for the methodologies for water and energy utility synergies. It may be the case that suitable regulatory standards are already in place in other industrial regions which would alter the required methodology to advance the reuse of inorganic by-products.

9.5.6 Community Support

Regional synergies can result in substantial benefits for the community and region, such as employment, reduced negative impact on the local environment through reduced dust and transport emissions, and increasing the regional security of water and energy through reduced industrial use. This is illustrated to various extents with some of the synergy examples discussed in this thesis (e.g. Section 4.3).

Similarly as for regulations, the community can be both a driver and barrier for regional synergy development. The drivers mainly apply to water and energy utility synergies while inorganic by-product synergies can experience a lack of community support.

The potential for future community opposition and public concern, which is often not based on sound science and can blow out of proportion, results in a strong disincentive for industries to pursue reuse of their inorganic by-products. Community (mis)perception on health and safety issues regarding the reuse of inorganic by-products is very important issue, and should not be underestimated (Van Beers and

Van Berkel 2005b. The same applies for government involvement and commitment. As part of the methodology for inorganic by-product synergies, an extensive stakeholder engagement process is being initiated in Kwinana that targets the realisation of a number of iconic high volume reuse opportunities which poses both a good business case and sustainability benefits.

It is recommended to review the community issues (possibly in conjunction with an assessment of the existing regulatory frameworks) before applying the customised methodology for inorganic by-product synergies in other industrial regions. This is less critical for the methodologies for water and energy utility synergies as these types of synergies are not subject to the high level of community and government scrutiny compared to inorganic by-product reuses. In contract, overall, there is widespread government and community support for the reuse of water and energy by industries.

9.5.7 Know-How and Expertise

The required skill level was identified as a weakness in the multi-criteria evaluation of the methodologies. This is mainly due to the comprehensive nature of the developed methodologies. It is anticipated that the customised synergy development methodologies based on the cleaner production framework (as discussed in this thesis) can be applied in other industrial areas by local research organisations and consultant/engineering companies operating in close proximity of the industrial estate.

In summary, industry facilitators need to have the following skills to successfully apply the developed methodologies for inorganic by-products, water, and energy synergies:

- Basic understanding of cleaner production and industrial ecology/regional concepts and their application in industry;
- Expertise and know-how of recovery technologies (e.g. materials, water, energy);

- Industry facilitation and communication skills ("speak the language of the industries"); and
- Strong analytical and assessment skills.

In parallel with this PhD research, research efforts have been undertaken to develop a user-friendly toolkit to assist industry facilitators and industries with the targeted and systematic identification and evaluation of potential synergy opportunities and assessment of technological recovery options (see Section 1.3). The development of the toolkit (CSRP Regional Synergy Toolkit) utilises the outcomes of the methodologies presented in this thesis. The software package will come with a detailed manual to guide the facilitator through the whole process. The aim of the toolkit is to reduce the required level of know-how and expertise to drive the synergy development process.

9.5.8 Access to Funding

External funding structures are required to enable the application of the novel methodologies presented in this thesis. This is particularly the case for the initial stages of the cleaner production framework (i.e. planning and organisation, pre-assessment, and assessment). This is because these stages provide the basis for the identification and evaluation of regional synergy and other industrial ecology opportunities. It is likely that industry funding will become available once opportunities with a sound business case have been identified. The investigations into these promising opportunities are conducted as part of the feasibility assessment stage.

If the initial stages do not deliver a listing of specific opportunities, the project is doomed to run out of funding. Therefore, the methodologies should be catered to the specific industry research needs and local issues affecting the industrial area (e.g. water scarcity, climate change policies, landfill levies).

In Kwinana, the initial research was funded by a cooperative research centre (Centre for Sustainable Resource Processing (CSRP), see Acknowledgements section). The foundation research resulted in the evaluation and implementation of promising synergy opportunities and industry funded research projects targeted towards specific reuse opportunities. The regional synergy development research in Kwinana has been extended with a further two years with increased financial support from the KIC and its members. Furthermore, the regulatory reuse standards and frameworks for inorganic by-products will most likely be developed as part of the CSRP Kwinana Inorganic By-Products Reuse Project.

9.5.9 Corporate Culture

Any industrial region will have industries with different corporate cultures, business and sustainability priorities, openness, and strategies. Not all industries may be enthusiastic initially to engage with other industries or get involved in a regional synergy study. Before applying the methodologies presented here, an assessment of the corporate cultures of the industries is recommended. It is unlikely that all industries in a given industrial area will see the business benefits of a regional synergies and/or cleaner production study. Therefore, it is crucial to start working with those that are and create success stories which will encourage other industries to participate later in the project.

The corporate culture, to a significant extent, affects the industry interest and emerging of industry champions to drive cleaner production/regional synergies projects forward. These are discussed in Section 9.5.3.

9.6 Water-Energy Nexus

As outlined earlier in this thesis (Section 2.9), water-energy nexus is the recognition of the depth of the links between the water and energy industry sectors (Marsh 2009). Water is critical for electricity generation and electricity is critical for water provision.

As part of the development and trial application of the customised methodologies to advance water and energy utility synergies, the water-energy nexus has been considered to a certain extent as part of the conventional business case evaluation of promising synergies (i.e. associated increases in energy consumption from promising water synergies, and visa versa with energy utility synergy opportunities).

Marsh (2009) notes that the water-energy nexus has largely been absent from reform discussions over the past two decades in Australia and internationally. Given that the limited understanding at policy and operational level, it is not surprising that the evaluation of the water-energy nexus in regional synergy development is an unexplored field of research. This thesis may touch upon the water-energy nexus, but further research will be required to address this topic sufficiently.

A key example of the water-energy nexus emerging from this research work is the identification of the opportunity for an evaporative water treatment and supply system utilising recovered energy from industry flue gases in Kwinana. Evaporative water treatment or desalination systems (e.g. multi-effect distillation) are proven technologies for regions and industries without readily access to fresh water. These technologies are normally driven by fossil fuels. The research on energy recovery from Kwinana flue gases (Chapter 8) revealed that the total energy release from Kwinana flue gases is estimated at approximate 6,300 TJ/yr, with up to 3,000 TJ/yr over 300^{o}C. This finding created interest from Kwinana industries to investigate the business and sustainability case to produce fresh water from seawater (desalination), utilising the energy embedded in industry flue gases. This package of work is currently being undertaken through the Centre for Sustainable Resource Processing as a spin-off project from the research presented in this thesis. Initial estimates show that very significant amounts of fresh water could be produced from flue gases energy (over 50 GL/yr). The industries recognise that the business drivers for water and energy conservation are changing rapidly, for example through increasing water/energy prices, the introduction of mandatory energy opportunity assessments (and their public disclosure), climate change policies, and upcoming carbon taxes. The concept of utilising industry waste heat to produce fresh water has significant potential to provide a win-win solution for dealing with increasing scarcity (and cost) of fresh water while improving the overall energy efficiency in the Kwinana Industrial Area.

9.7 Conclusions from Methodology Evaluation

Based on the comparative review, the cleaner production framework is evidently very valuable and suitable for the development of customised methodologies for regional synergy identification, evaluation, and implementation. The common elements of synergy development are present in all three methodologies (i.e. awareness and recruitment, data collection, analysis / synergy identification, and implementation & continuation). The methodologies applied to advance inorganic by-product, water, and energy synergies have been developed to meet the specific research needs of the stakeholders involved (i.e. industries, government) and the industrial region as a whole. The cleaner production framework is not a driver for synergy development perse, but rather should be regarded as a flexible approach to advance synergy development targeted towards specific local research needs.

The multi-criteria evaluation revealed that all three methodologies have been effective in delivering valuable outcomes for the industries involved and other stakeholders (e.g. government). Further strengths of the methodologies include the added-value to stakeholders and their participation, transparency and flexibility (systematic approach). The main weakness of the methodology concerns the time investment. However, with the methodologies for inorganic by-products, water, energy synergies developed, it is anticipated that the identification and preliminary evaluation of the promising synergy opportunities in other industrial regions can be carried out within a shorter period of time. However, this is subject to the region-specific characteristics such as corporate culture, government and community support. Suggestions to improve the performance and required time-investment to apply the methodologies are discussed in the next chapter.

The evaluation against the requirements for regional synergy development (based on the results from the Kwinana case-study) showed that a set of parameters must be addressed before applying the customised methodologies for inorganic by-product, water, and energy synergies in industrial regions elsewhere in the world. These parameters include: distances between the industries, number and diversity of industries, level of industry interest and identification of industry champions, the presence and functioning of an industry organisation, current regulations applicable to regional synergies, level of community support, availability of know-how and expertise, access to funding, and corporate culture. Further research will be required to validate and quantify the requirements and recommendations.

Overall, it has been demonstrated, through the assessment of the requirements for methodology application elsewhere, that no significant barriers or impediments exists which would prohibit the utilisation of the developed methodologies within other industrial areas internationally.

10 CONCLUSIONS AND RECOMMENDATIONS

10.1 Introduction

This chapter summarises the main conclusions and lessons from the research, provides recommendations for the improvement of the methodologies developed, and specifies the contributions made to the practice of, and research in, the field of industrial ecology. Future research directions are provided at the end of this chapter.

10.2 Research Conclusions

The overall aim of this research was to research the effectiveness of drawing common elements of regional synergy development into an overall framework generally used for the implementation of cleaner production, to assist industries in heavy industrial areas with advancing regional synergy opportunities. This framework was the basis for the development of customised methodologies for progressing regional synergies in three key sustainability themes in the case-study area (Kwinana Industrial Area): inorganic by-products, water, and energy.

The lessons and conclusions from the research to address the project aim are as follows:

§ Literature review (Chapter 2): The concept of regional synergies is an emerging discipline of research and practice in the field of industrial ecology. The realisation of regional synergies in industrial areas with intensive minerals processing provides a significant avenue towards sustainable resource processing. Given the absence of appropriate methodologies to develop regional synergies, the cleaner production framework seems to be a pragmatic and constructive approach to assist industries with the identification, evaluation, and implementation of regional synergy opportunities. The common elements of regional synergy development (awareness and recruitment, data collection, analysis / synergy identification, implementation and continuation) should to be incorporated to make the cleaner production framework suitable for the purposes of this study. The KIA was an ideal case-study area for the research undertaken. A significant number of regional synergies are already in place providing a range of sustainability benefits to the industries involved and the region as a whole. Favourable features for further regional synergy development in Kwinana include the Kwinana Industries Council which provides a platform for industry collaboration, and the diversity of mostly non-competitive industries located in close proximity.

§ <u>Research gaps (Chapter 3):</u> The development and implementation of regional synergies is a valid and valuable contribution to the sustainable development of heavy industrial areas. However, the main focus of regional synergies research is on knowledge building, studying historical development and examining existing regional synergies. There is a lack of practically applied research to industries in heavy industrial areas with the development of new synergies. Regional resource synergies have so far developed opportunistically in the absence of specific methods for synergy option generation. There is also a lack of attention given to technological and engineering challenges specifically associated with regional synergy development. Without rigorous, systematic and practical approaches to regional synergy identification, development and implementation, it is likely that potential opportunities would be missed.

§ <u>Review of existing synergies in the case-study area (Chapter 4):</u> The research has confirmed the close collaboration and integration that already exists in the KIA, which has initially developed in response to perceived business opportunities and environmental and resource efficiency considerations. The existing regional synergies in Kwinana greatly exceed ‘business-as-usual’, and are more diverse and significant than reported for other heavy industrial areas. The benefits of the existing synergies often go well beyond the conventional business case benefits. Resource security, increased efficiency, lower operational costs, reduced landfill disposal, and employment are some of the key benefits from existing regional synergies in Kwinana. Many diverse regional synergy opportunities still exist in the KIA, mostly in three broad areas: industrial inorganic by-products, water, and energy. Proven technology, a convincing business case, and license to operate are key success factors that determine whether or not a regional synergy will be implemented by industry. It is clear that a wide range of drivers and barriers exist which are influenced by a diverse set of stakeholders (e.g. companies, regulators, community). In addition, trigger events played an important role in synergy developments in Kwinana. The complete set of drivers, barriers, and trigger events, rather than one specific aspect, determines the business and sustainability case of a regional synergy opportunity. Overall, it is clear that there is no "one-size-fits-all" approach to develop regional synergies; each synergy is unique in terms of its drivers, barriers, business case, and sustainability benefits.

§ Methodology framework (Chapter 5): The common elements of synergy development (awareness & recruitment, data collection, analysis and synergy identification, implementation and continuation) can be merged into a framework generally used for the implementation of cleaner production in industries. The framework provided the basis for developing customised methodologies for advancing regional resource synergies for the three key priority areas: inorganic by-products, water, and energy.

§ Methodology to advance inorganic by-product synergies (Chapter 6): Significant potential exists for the establishment of large scale reuse of inorganic by-products available in the KIA. A coordinated stakeholder methodology is being facilitated and applied that targets the realisation of a number of iconic and short-term recovery opportunities which have both a good business and sustainability case. Kwinana industries are experiencing obstacles in obtaining governmental approvals for reuse of their inorganic by-products and use of alternative fuels. Recent developments indicate that the local and state governments have an increasing awareness and understanding of the resource value of the large volume inorganic by-products available in the KIA. Discussions with various governmental departments are being held to assess the means for streamlining the regulatory approval processes, and implement a standardised review process. A review of national and international experiences and practices has revealed that inorganic by-products are widely accepted and reused as alternative raw materials for building and construction, agriculture, and resource recovery. The regulatory framework and reuse standards being applied in numerous countries (e.g. USA, The Netherlands, France, Sweden, Denmark, Germany) encourage, and in some cases even enforce, the reuse of inorganic by-products. This is not yet the case in Western Australia where the lack of reuse protocols and standards prevents or delays the implementation of such reuses on a large scale and routine basis.

§ <u>Methodology to advance water utility synergies (Chapter 7):</u> There is widespread commitment from the industries and the KIC to achieve greater reductions in water consumption and discharges, and explore alternative water sources. A conventional water mapping and workshop methodology (based on the cleaner production framework) was undertaken to identify and evaluate promising water synergy opportunities. The efforts to secure a sustainable water source on the short/medium term and long term show that a diversity of solutions are being explored, evaluated and, if found feasible, implemented by the Kwinana industries. Numerous, diverse water synergy opportunities still appear to exist. The research to date has assisted the industries and KIC with the identification and development of promising water synergies. The type and level of assistance provided depends entirely on the specific research needs of the involved industries. Significant progress has been made so far to further develop a set of promising new synergies. One synergy is being implemented so far, and the implementation of other promising synergies is anticipated for the near future.

§ <u>Methodology to advance energy utility synergies (Chapter 8):</u> The aim of the customised methodology for energy was to arrive at potentially feasible energy recovery opportunities from Kwinana flue gases. The focus of the methodology was on flue gases due to the limited recovery potential for other energy losses (e.g. steam, water) in terms of energy content and temperature. The trial application of the method in Kwinana demonstrated its value in contributing to the collaborative development of energy recovery opportunities. The underlying assumptions and formulas related to the various technologies can be further improved if better qualitative data become available. The methodology is not a stand-alone solution but should be used as a supplementary instrument to streamline the identification and evaluation of energy recovery opportunities and associated technologies. Although the methodology is specifically developed around energy losses from flue gases, it can be applied to other energy sources as well, such as hot water or steam (assumptions and formulas will need to be modified accordingly). The research outcome is a set of on-site and collaborative recovery opportunities that were subjected to preliminary technical, economic, and environmental assessments. The finding shows that there is significant potential to mitigate CO_2 emissions through energy recovery from Kwinana flue gases by applying technologies to convert the embedded energy into useful thermal and electrical applications. It is acknowledged that on-site opportunities should be explored first before going ahead with collaborative industry initiatives. From the analysis, it is clear that carbon taxes of A$25 to A$50 per tonne CO_2 are required to make a significant positive impact on the economic viability of energy recovery opportunities. The regional synergies research in the Kwinana is now facilitating the engagement between the Kwinana industries and external expert organisations to build upon the results of the flue gas methodology, and to assist with feasibility assessments of promising reuse opportunities (ongoing work).

§ <u>Evaluation of applied methodologies (Chapter 9):</u> The cleaner production framework proved to be very useful and appropriate for the development of customised methodologies for regional synergy identification, evaluation, and implementation. The common elements of synergy development are present in all three methodologies (i.e. awareness and recruitment, data collection, analysis / synergy identification, implementation and continuation). The cleaner production framework is not a driver for synergy development perse, but rather should be regarded as a flexible approach to advance synergy development targeted towards specific research needs of the stakeholders involved (i.e. industries, government) and the industrial region as a whole. The multi-criteria evaluation revealed that all three methodologies have been effective in delivering valuable outcomes for the industries and other stakeholders. Further strengths of the methodology include the added-value to stakeholders and their participation, transparency and flexibility (systematic approach). The main weakness of the methodologies concerns the time investment. However, with the methodologies developed, it is anticipated that the identification and preliminary evaluation of the promising synergy opportunities in other industrial regions can be done in a significantly shorter time period. The evaluation against the requirements for regional synergy development showed that a set of parameters must be addressed before applying the customised methodologies in industrial regions elsewhere in the world. These parameters include: distances between the industries, number and diversity of industries, level of industry interest and identification of industry champions, the presence and functioning of an industry organisation, current regulations applicable to regional synergies, level of community support, availability of expertise, access to funding, and corporate culture.

10.3 Regional Synergy Development Action Program and Strategy

This thesis includes a thorough analysis of the barriers and drivers for regional synergy development in Kwinana (Section 4.4), and assessment of the requirements to apply the customised methodologies for advancing inorganic by-product, water, and energy synergies in other industrial regions (Section 9.5). Based on the experiences and the method development process outlined in this thesis, Table 10.1 has been produced to conclude with a solid, generic action program to overcome the barriers and enhance the drivers / requirements for regional synergy development.

Table 10.1: Action Program for Enhancing Synergy Drivers and Reducing Synergy Barriers

Category	Indicative Driver / Barrier Criteria	Possible Action Program to Enhance Drivers and Reduce Barriers	Actions Influence
Distances between industries	*Driver when:*		
	• Inorganic by-products = distance < 2.5 km	Promising inorganic by-product synergy opportunities can include a broad(er) range of reuse applications, including lower value applications and those that may require processing	Scope of work
	• Water = distance < 1 km	In addition to aggregated (larger) water flows (e.g. treated effluents), work can include separated water streams such as cooling water, process water, boiler blowdown	
	• Energy = distance < 0.5 km	For any energy synergy study, priority should be on energy flows with highest temperatures and energy contents (TJ/yr)	
	Barrier when:		
	• Inorganic by-products = distance > 5 km	Focus on higher value applications, low cost process technologies, and optimisation of logistics	Scope of work
	• Water = distance > 2.5 km	Focus solely on large water flows in the industrial area (e.g. treated effluents), not on smaller separated flows (e.g. boiler blowdown)	
	• Energy = distance > 1 km	Do not focus on energy utility synergy opportunities between existing industries, rather focus on on-site opportunities	
Number and diversity of industries	*Driver when:*		
	• > 10 industries with < 25% in same industry sector	Use diversity of industries as a platform to match sources (producers) and potential sinks (users) of resources (by-products, water, energy) in the region	Scope of work
	Barrier when:		
	• < 5 industries with > 50% in same industry sector	It is critical to acquire involvement from all industries in the region in order to achieve “critical mass” for regional synergy development Focus on creation of economies of scale (e.g. shared capital investments / facilities) as industries are likely to have similar resource or treatment needs (e.g. water treatment)	Scope of work

Category	Indicative Driver / Barrier Criteria	Possible Action Program to Enhance Drivers and Reduce Barriers	Actions Influence
Industry interest and industry champions	*Driver when:*		
	• At least three industries have expressed interest to develop synergies in industrial area • Industry champions within at least three key industries have been identified	Work with interested industries and industry champions to identify and develop promising synergy opportunities Use industry champions and interested industries to build up further momentum for regional synergy development	Scope of work
	Barrier when:		
	• Limited industry interest to develop synergies in industrial area (no perceived potential, or all synergy opportunities have already been achieved) • Industry champions within at least three key industries have not been identified	Need to attract industry interest before start of synergy development process. Create interest through: • Synergy examples from similar (inter)national industrial areas (e.g. benefits, business case, achievability) • Identification of industry champion(s) who can assist with gearing up industry support for regional synergies • Uncover regional synergies already existing in the industrial area	Scope of work
Industry organisation	*Driver when:*		
	• There is a formalised industry organisation operating in the region with active input from individual companies	Use industry organisation as a platform for application of methodologies, e.g.: • Review of current and emerging regional issues and opportunities • Identification of priority areas for synergy development • Steering group meetings • Opportunity identification and development workshops	Synergy development platform
	Barrier when:		
	• There is no formal or informal body coordinating or representing or industries operating in the region	Create a project steering group with membership/input from key industries operating in the industrial region	Synergy development platform
Regulations	*Driver when:*		
	• Relatively high costs for disposal: o Landfill (inorganic by-products) o Sewage (effluent)	Priority should be given to high volume resources (by-products, water, energy) which are currently being disposed while their reuses are encouraged by the existing regulatory framework	Scope of work

Category	Indicative Driver / Barrier Criteria	Possible Action Program to Enhance Drivers and Reduce Barriers	Actions Influence
	o Emission to atmosphere (energy) • Existing regulatory framework encourages the uptake of regional synergy development, or at least does not discourage its uptake		
	Barrier when:		
	• Relatively low costs for disposal: o Landfill (inorganic by-products) o Sewage (effluent) o Emission to atmosphere (energy) • Existing regulatory framework does not encourage or facilitate the uptake of regional synergies on a routine basis	Focus on reuse applications of high volume resources which are not so much affected by existing regulatory frameworks If there is significant buy-in from industry and government stakeholders, work could focus on the development of new regulatory guidelines that will facilitate the uptake of synergy opportunities with a proven sustainability case	Scope of work
Community	*Driver when:*		
	• Community is supportive of regional synergy development, and recognisee the benefits of implementing these	Focus on synergy opportunities which have strong community support, and use these as a platform to gain (further) industry and government interest	Scope of work
	Barrier when:		
	• There is community opposition and public concern about reuse of industrial inorganic by-products, water, and energy	Focus on synergy opportunities which are not likely subjected to community misperceptions or opposition Alternatively, engage community throughout regional synergy development process, and educate community on the science behind regional synergies	Scope of work
Know-how and expertise	Driver when:		
	• Required know-how and expertise is available locally to progress the development of regional synergies in an industrial area	Utilise capabilities of local organisations and facilities (e.g. universities), and promote collaborative research to build upon strengths of individual parties	Synergy development platform
	Barrier when:		
	• Required know-how and expertise is not available locally to progress the development of regional synergies in an industrial area	Utilise (inter)national leading research bodies and service providers to build-up local capability and skill level	Synergy development platform
Access to	Driver when:		

Category	Indicative Driver / Barrier Criteria	Possible Action Program to Enhance Drivers and Reduce Barriers	Actions Influence
funding	• Seed funding is available to undertake regional synergy development work / research	Research should be catered to the specific industry research needs and local issues affecting the industrial areas in order to provide a basis to acquire continued funding	Synergy development platform
	Barrier when:		
	• No or limited funding is available to undertake regional synergy development work / research	Undertake an initial scoping study to review the potential for regional synergy development in an industrial area. Such a scoping study could be undertaken with limited resources, and could involve the initial stages of the cleaner production framework (planning & organisation, and pre-assessment) The funding for such a scoping study would likely come from participating industries operating in the region. Since the total costs are shared, the costs for individual companies will be relatively low	Synergy development platform
Corporate culture	Driver when:		
	• "Open" culture: Industries are willing to communicate openly and collaborate with their neighbouring industries on issues relevant to the synergy development process (subject to confidential and commercial issues)	Utilise open corporate culture of the industries as a key mechanism for the identification and evaluation of synergy opportunities, e.g.: • Industry workshops • Sharing of work undertaken in the past by individual industries	Synergy development platform
	Barrier when:		
	• "Closed" culture: Industries are hesitant to communicate openly with their neighbouring industries on issues relevant to the synergy development process (subject to confidential and commercial issues)	Attempt to create an environment in which are industries (and other stakeholders) are willing to share information and collaborate, e.g. through: • Limit discussions to issues that are of key importance to synergy development process • Development of personal relationships between employees of individual industries and other stakeholders • Set up confidentiality agreements	Synergy development platform

Table 10.1 illustrates that the general action programs can influence:

- Synergy development platform: mechanisms that assist or enable the development of regional synergies.
- Scope of work: elements or priorities that should be addressed as part of the facilitated synergy development process, including the types of synergies to be targeted (e.g. by-product versus utility synergies).

Integrating the action program outlined in Table 10.1 and elements outlined above with the customised methodologies to advance inorganic by-product, water, and energy synergies provides a generic and overarching strategy for the development of regional synergies in heavy industrial areas (Figure 10.1).

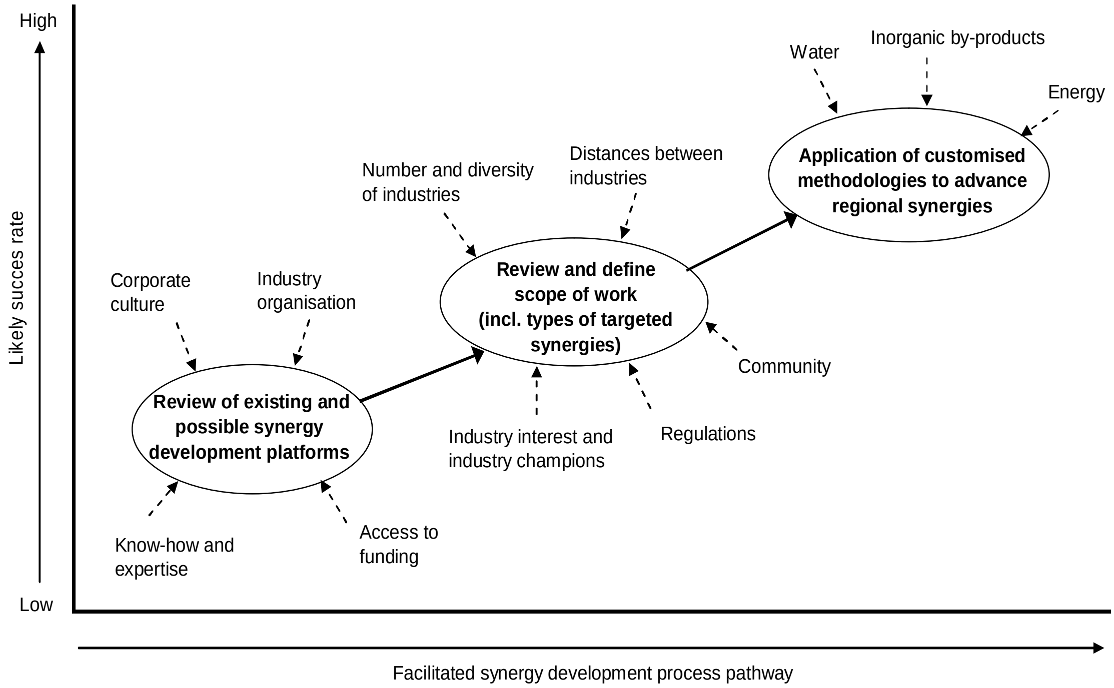

Figure 10.1: Proposed Regional Synergy Development Strategy

Figure 10.1 demonstrates that a review of existing and possible synergy development platforms in an (heavy) industrial area should take place first, feeding from an evaluation of corporate cultures, industry organisation(s), available know-how and expertise, and access to funding. A review of the scope of works can then follow taking into account the number and diversity of industries, distances between industries, industry interest, industry champions, existing regulations, and the community perceptions and issues. After reviews of the existing synergy development platforms and scope of works have been completed, a justified and well-informed decision can be made on which elements of the customised methodologies should be applied, and how this can best be done given the unique features of the industrial region under investigation.

10.4 Research Contributions

It is thought that the development of these customised methodologies and their application in the case-study area have made a significant contribution to the following parties:

- Academia: A significant enhancement of existing theories and contributions of new theories on industrial ecology and regional synergy development;
- Industry: Research support to achieve greater efficiencies in energy, water, and materials consumption and reductions in waste and emissions generation;
- Government: Recommendations for improving resource and sustainability policies;
- Community: Illustrated community benefits of implemented synergies (e.g. improved air emissions, employment, scheme water conservation); and
- Facilitators for regional synergy development: Recommendations and applied methodologies to assist regional synergy development in heavy industrial areas.

10.5 Recommendations for Improvement of Methodologies

Suggestions to improve the performance of the methodologies for inorganic by-product, water, and energy synergies in heavy industrial areas are summarised in the table below. The suggestions are largely based on the method evaluations described in Chapter 9 ‘Evaluation of Applied Methodologies’. The suggestions aim to eliminate the weaknesses identified and further enhance the strengths of the methodologies developed.

Table 10.2: Recommendations for Improvement of Methodologies

Recommendations		Improvement	Phase	Theme
1	Incorporate the methodologies, including underlying formulas and assumptions, into a user-friendly software package with a detailed manual to guide the facilitator through whole process. Such toolkit is being developed through the CSRP (see Section 1.3 and (Van Beers et al. 2007c).	Time investment, efficiency, required skill level, systematic approach	All	Inorganic by-products, water, and energy
2	Develop a comprehensive and inclusive approach to demonstrate and account for the economic, social, and environmental benefits of the life cycle of a new synergy opportunity. As part of an ARC research project on synergy enabling mechanisms, a novel approach on triple bottom line accounting of regional synergies is being developed (Kurup et al. 2005).	Effectiveness, added value to stakeholders	Feasibility studies, implementation and continuation	Inorganic by-products, water, and energy
3	Work with standardised and flexible confidentiality agreements or consent forms that suit the specific purpose and scope of the project. These agreements were mostly put into place to enable the sharing of sensitive or commercial information between industries.	Time investment, stakeholder participation	Pre-assessment, assessment, feasibility studies	Inorganic by-products, water, and energy
4	Ensure continuation of the synergy development and research outcomes after the supporting research has been completed. This could be done by encouraging industry ownership of the promising synergy opportunities. Ownership is achieved when the industry becomes aware of the business case and the sustainability benefits of the opportunity.	Effectiveness, added value to stakeholders	Implementation and continuation	Inorganic by-products, water, and energy
5	Any industrial region will have industries with different corporate cultures, business and sustainability priorities, openness, and strategies, etc. Not all industries may be enthusiastic initially to engage with other industries or get involved in a regional synergy study. It is recommended to start working with those that are and create success stories which will encourage other industries to participate later in the project.	Effectiveness, efficiency, stakeholder participation	Pre-assessment, assessment, feasibility studies	Inorganic by-products, water, and energy
6	The methodologies described in this thesis could be applied in other industrial areas worldwide. The methodologies should be regarded as flexible frameworks which should be tailored to the specific research needs of the industries involved and the region as a whole. A selection of methodology components may be used if significant work has been done in certain areas. It is important not to duplicate efforts in terms of efficiency, creation of success stories, and added value to stakeholders.	Time investment, efficiency, added value to stakeholders	All	Inorganic by-products, water, and energy

	Recommendations	Improvement	Phase	Theme
7	Following the hierarchy of waste management priorities (in order of preference: avoidance, reduction, segregation, reuse, recycling, treatment, and disposal), preference should be given first to on-site (cleaner production) opportunities before considering regional synergy options. It is recommended to incorporate and formalise a review of cleaner production versus regional synergy opportunities in the pre-assessment phase of the customised methodologies.	Effectiveness, efficiency	Pre-assessment	Inorganic by-products, water, and energy

10.6 Further Research Directions

This research highlighted that the cleaner production framework can be used as an effective framework to assist industries in heavy industrial areas with advancing synergy opportunities. A number of areas where further research is believed to be necessary and highly important have been identified.

Based on the research findings of this research, recommended future research includes:

1. Follow-up on the recommendations to improve the performance of the customised methodologies developed and applied as part of the research presented in this thesis (see Section 10.5).

2. Quantify the requirements and recommendations to apply the customised methodologies for inorganic by-product, water, and energy synergies in heavy industrial areas elsewhere in the world (as discussed in Section 9.5).

3. Continue the collaborative research work on the development of governmental standards and guidelines for the reuse of inorganic by-products in Kwinana. These need to be customised depending on the particular by-product material and reuse conditions, and would enable the safe reuse of materials and assist companies in showing that they have met the required regulatory standards (see Sections 6.3.9 and 6.3.11).

4. The methodologies presented in this thesis were developed based on the industry needs in the case-study area. The methodologies can be applied elsewhere, however will likely need to be modified based on the local research needs, conditions (e.g. regulations), and type and number of industries located in the industrial area under investigation.

5. Further development of practical, customised methodologies and tools, to support the uptake of industrial ecology practices by industries (e.g. triple-bottom-line or sustainability assessments).

6. The research presented here did not address the identification and evaluation of supply chain and service synergies in heavy industrial area (outside scope of this research, see Section 1.3). There is a potential to develop customised methodologies for these types of regional synergies as well.

7. Development of enabling mechanisms that encourage the implementation of promising regional synergy or industrial ecology opportunities that are not part of the industries' day-to-day core business (e.g. (Harris 2008)).

8. Establishment of funding structures to conduct foundation research work in heavy industrial areas that will provide the basis for the identification and evaluation of regional synergies and other industrial ecology opportunities (e.g. the application of the methodologies outlined in this thesis).

9. Investigation into the implications of the water-energy nexus in synergy identification and development processes, including the evaluation of trade-offs in savings in water versus energy consumption (as discussed in Section 9.6).

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Reference Statement:

APPENDIX 1: LIST OF CURRENT BY-PRODUCT SYNERGIES IN KWINANA

#	Output from	Input to	Material and Application
1	Alcoa World Alumina	Ecomax	Bauxite residue for sewage effluent treatment
2	Alcoa World Alumina	Worm farm	Crib room and canteen food scraps
3	Australian Fused Materials	Mineral admixture in high strength and durable concrete	Silica fume
4	Australian Fused Materials	Unknown	Graphite electrodes
5	BGC Cement Kwinana / Canningvale	BGC Blokpave	Concrete pavers, cylinders, tiles (product testing by-products)
6	BGC Cement Kwinana / Canningvale	BGC Insulation plant	Cardboard
7	Mineral processing plant	BGC Cement Kwinana / Canningvale	Blast furnace slag
8	BP Refinery Kwinana	BOC Gases	Hydrogen for CUTE (Clean Urban Transport for Europe) Bus Project and others
9	BP Refinery Kwinana	Cockburn Cement	Recycling of spent RCU catalysts in cement manufacturing process
10	BP Refinery Kwinana	Oackford Organics	Phosphorous content of spent CPU catalysts is leached out at Oakford Organics and used as compost addition
11	BP Refinery Kwinana	Coogee Chemicals	Elemental sulphur
		Kwinana Nickel Refinery	
12	BP Refinery Kwinana	Kwinana Nickel Refinery	Hydrogen (back-up supply for KNR)
13	Cockburn Cement	Tiwest Pigment Plant Kwinana	Lime kiln dust for chlorine removal
		HIsmelt	Lime kiln dust for sulphur dioxide removal
14	Cockburn Cement	Various companies	Lime kiln dust for soil conditioning
15	Griffin Coal	Cockburn Cement	Overburden of Collie coal pits (shale)
16	Coogee Chemicals	Nufarm Coogee	Supply and use of 98% sulphuric acid as drying agent and supply back at 80% concentration for on sale in commercial markets
	Nufarm Coogee	Coogee Chemicals	
17	CSBP	Air Liquide	Conversion of process carbon dioxide into commercial gases
18	CSBP	Air Liquide	Conversion of by-product hydrogen into commercial gases
19	CSBP	BOC Gases	Conversion of carbon dioxide into commercial gases

#	Output from	Input to	Material and Application
20	CSBP	Alcoa World Alumina	Carbon dioxide to blend in pipeline with bauxite residue to sequest carbon dioxide emissions and neutralise bauxite residue
21	CSBP	Alcoa World Alumina	Gypsum stockpiled from closed phosphoric acid plant for application in residue area remediation
22	CSBP	BP Refinery Kwinana	Methyl diethyl amine (MDEA)
		Composting facility	
23	Doral Specialty Chemicals	Coogee Chemicals	3-5% solution of ammonium chloride (wastewater stream) as feedstock for 25% NH4Cl production
		Iluka	3-5% solution of ammonium chloride (wastewater stream)
24	Tiwest Pigment Plant Kwinana	Coogee Chemicals	Conversion of waste hydrochloric acid from pigment production into ammonium chloride for synthetic rutile production
	Coogee Chemicals	Tiwest Synthetic Rutile Plant (Chandala)	
25	Water Corporation Woodman Point WWTP	Feedcrop farmers	Use of biosludge from anaerobic digester as soil conditioner
26	Verve Energy Kwinana Power Station	Greenacre Turf Farm	Fly ash for soil amendment
		Construction industry	Fly ash for brick and concrete production
27	Kwinana Nickel Refinery	Air Liquide	Conversion of waste carbon dioxide into commercial gasses
28	Kwinana Nickel Refinery	CSBP	Hydrogen
29	Kwinana Nickel Refinery	BOC Gases	Conversion of by-product carbon dioxide into commercial gasses
30	Kwinana Nickel Refinery	CSBP	Ammonium sulphate used in fertiliser production
		Summit Fertilisers	
31	Kwinana Nickel Refinery	Murrin-Murrin nickel mine	Process residue
32	Kwinana Nickel Refinery	Murrin-Murrin nickel mine	Waste sulphur

APPENDIX 2: LIST OF CURRENT UTILITY SYNERGIES IN KWINANA

#	Output from	Input to	Material
1	Alcoa World Alumina	BOC Gases	Electricity
2	BP Refinery Kwinana	CSBP	Wastewater to CSBP wetland cells
3	BP Refinery Kwinana	CSBP	Sea cooling water
	CSBP	BP Refinery Kwinana	
4	BP Refinery Kwinana	Kwinana Cogeneration Plant	Excess fuel gas used to fire cogeneration power plant
	Kwinana Cogeneration Plant	BP Refinery Kwinana	Steam generated by cogeneration power plant
	Kwinana Cogeneration Plant	BP Refinery Kwinana	Electricity generated by cogeneration power plant
	Kwinana Cogeneration Plant	BP Refinery Kwinana	Waste water generated by cogeneration power plant
5	Coogee Chemicals	CSBP	Process and treated wastewater from Coogee Chemicals in CSBP
6	CSBP	Tiwest Pigment Plant Kwinana	Supply of excess bore water
7	HIsmelt	Air Liquide	Excess process steam
8	Tiwest Pigment Plant Kwinana	Verve Energy Cogeneration Plant	Pressurised air
	Tiwest Pigment Plant Kwinana	Verve Energy Cogeneration Plant	Reverse osmosis water
	Tiwest Pigment Plant Kwinana	Verve Energy Cogeneration Plant	Potable water
	Verve Energy Cogeneration Plant	Tiwest Pigment Plant Kwinana	Electricity generated by cogeneration power plant
	Verve Energy Cogeneration Plant	Tiwest Pigment Plant Kwinana	Steam generated by cogeneration power plant
	Verve Energy Cogeneration Plant	Tiwest Pigment Plant Kwinana	Wastewater
9	Tiwest Pigment plant Kwinana	Nufarm Coogee	Electricity
	Tiwest Pigment Plant Kwinana	Nufarm Coogee	Steam
	Tiwest Pigment Plant Kwinana	Nufarm Coogee	Potable water
	Nufarm Coogee	Tiwest Pigment Plant Kwinana	Waste water (boiler blowdown + reverse osmosis brine)

#	Output from	Input to	Material
10[4]	Water Corporation Kwinana Water Reclamation Plant	CSBP	High grade industrial processing water from Woodman Point Wastewater Treatment Plant - Kwinana Water Reclamation Project
	Water Corporation Kwinana Water Reclamation Plant	BP Refinery Kwinana (planned)	
	Water Corporation Kwinana Water Reclamation Plant	Kwinana Cogeneration Plant (planned)	
	Water Corporation Kwinana Water Reclamation Plant	HIsmelt	
	Water Corporation Kwinana Water Reclamation Plant	Tiwest Pigment Plant Kwinana	
	CSBP	Water Corporation Kwinana Water Reclamation Plant	Industrial water being disposed via Sepia Depression Ocean Outlet Landline (SDOOL) - Kwinana Water Reclamation Project
	BP Refinery Kwinana	Water Corporation Kwinana Water Reclamation Plant (planned)	
	Kwinana Cogeneration Plant	Water Corporation Kwinana Water Reclamation Plant (planned)	
	HIsmelt	Water Corporation Kwinana Water Reclamation Plant	
	Tiwest Pigment Plant Kwinana (planned)	Water Corporation Kwinana Water Reclamation Plant	
11	Water Corporation Kwinana wastewater treatment plant	Alcoa World Alumina	Recycled water from Kwinana wastewater treatment plant (via ground water)
		Others	
12	Wesfarmers LPG	Kleenheat Gas	Condensate water
13	Verve Energy Kwinana Power Station	Verve Energy Cockburn Power Station	Excess demineralised water from treatment of fly ash pond leachate
14	Verve Energy Kwinana Power Station	CSBP	Reverse osmosis water
15	Verve Energy Cockburn Power Station	Verve Energy Kwinana Power Station	Boiler blowdown water for recycling

[4] Infrastructure and facility for KWRP have been completed and KWRP water is being supplied to selected users. Contractual arrangements between Water Corporation and some KWRP users are still being finalised.

APPENDIX 3: KWINANA INPUT & OUTPUT DATABASE

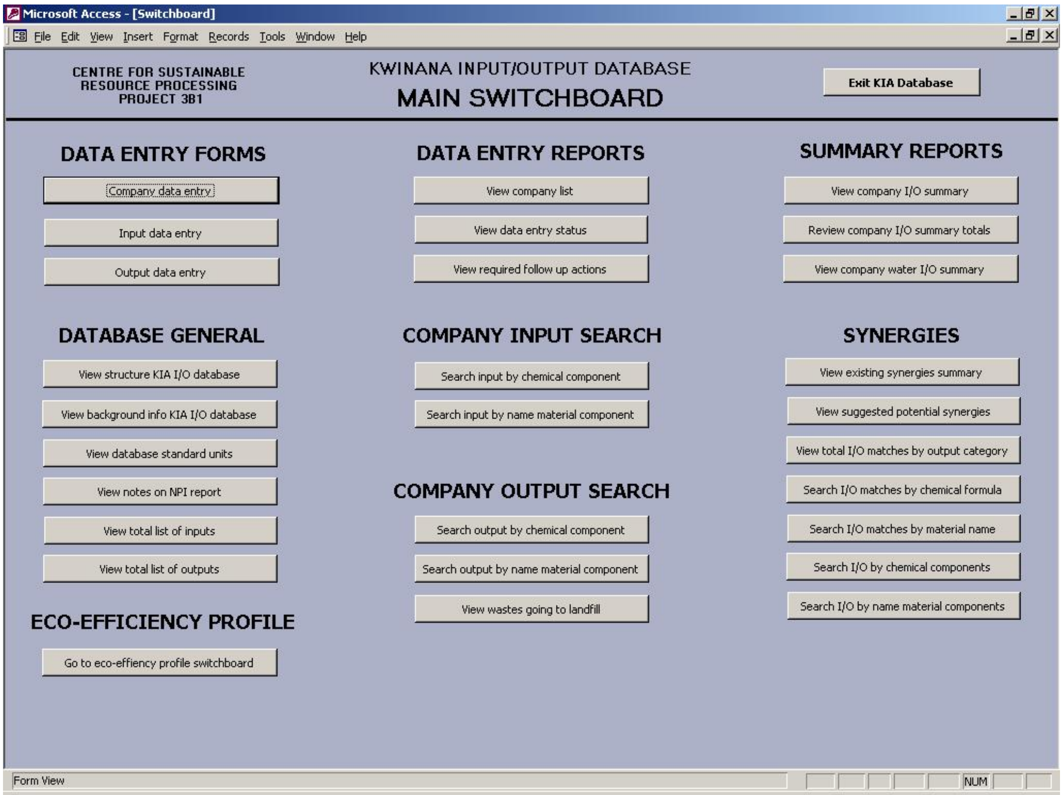


Figure: Main Switchboard of Kwinana Database

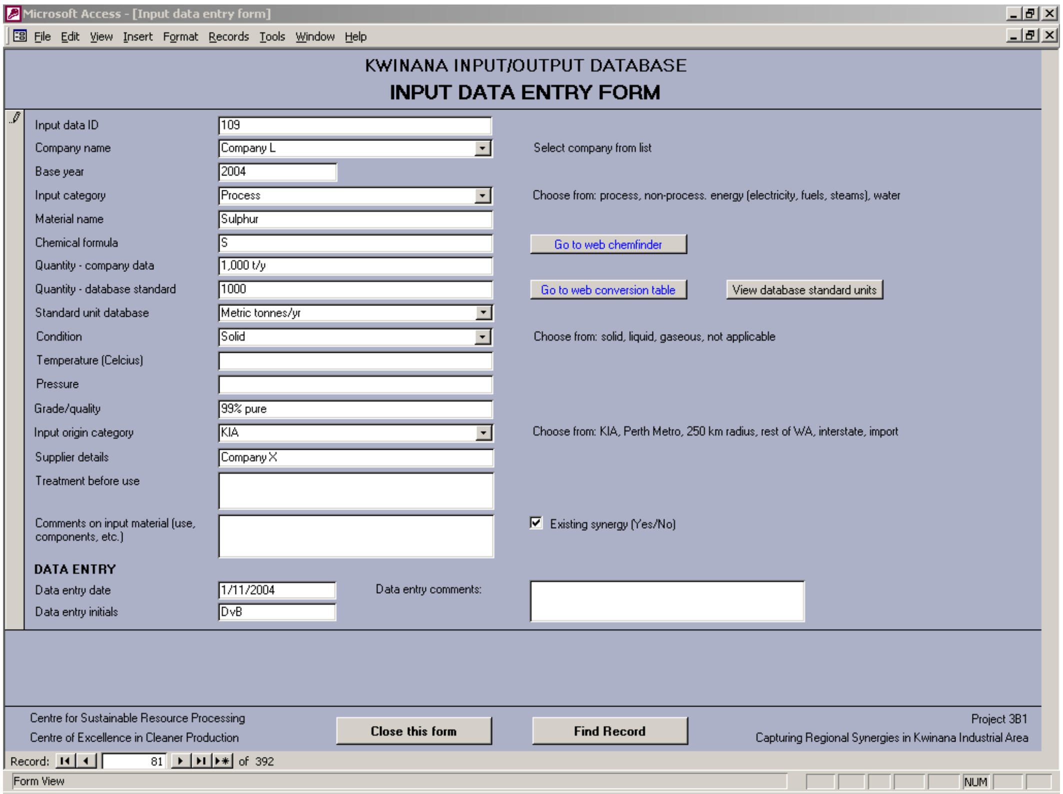
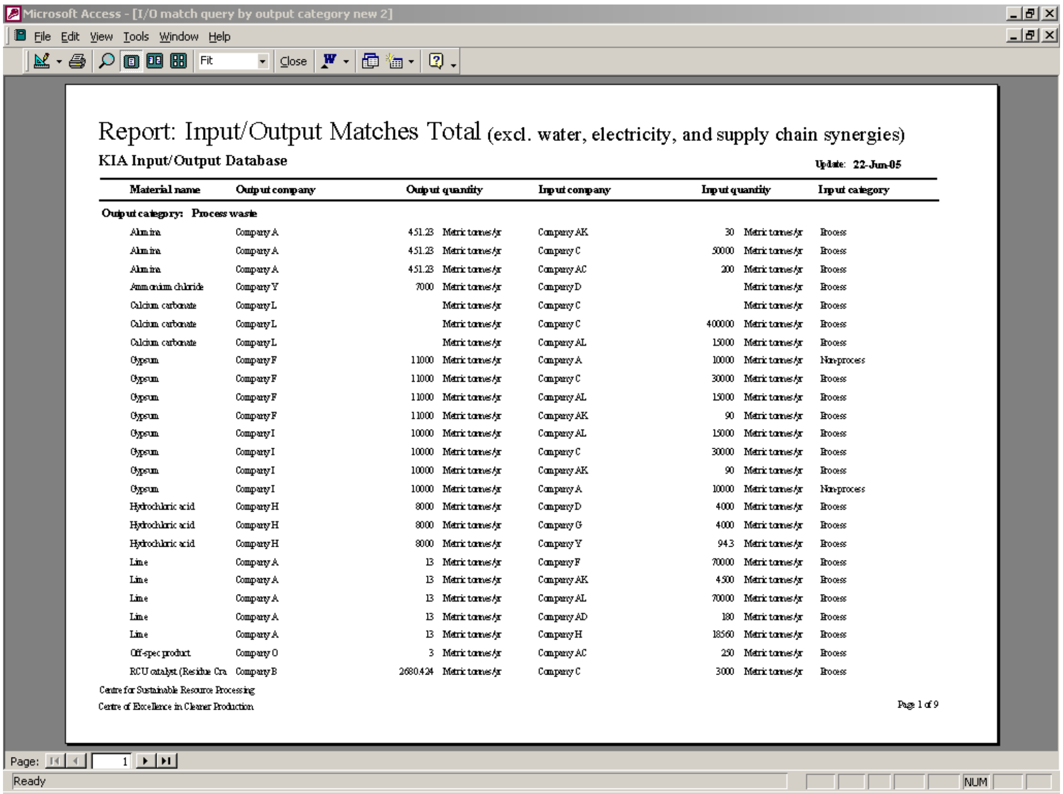


Figure: Example of Data Entry Form in Kwinana Database



Report: Input/Output Matches Total (excl. water, electricity, and supply chain synergies)

KIA Input/Output Database

Update: 22-Jun-05

Material name	Output company	Output quantity		Input company	Input quantity		Input category
Output category: Process waste							
Alumina	Company A	451.23	Metric tonnes/yr	Company AK	30	Metric tonnes/yr	Process
Alumina	Company A	451.23	Metric tonnes/yr	Company C	50000	Metric tonnes/yr	Process
Alumina	Company A	451.23	Metric tonnes/yr	Company AC	200	Metric tonnes/yr	Process
Ammonium chloride	Company Y	7000	Metric tonnes/yr	Company D		Metric tonnes/yr	Process
Calcium carbonate	Company L		Metric tonnes/yr	Company C		Metric tonnes/yr	Process
Calcium carbonate	Company L		Metric tonnes/yr	Company C	400000	Metric tonnes/yr	Process
Calcium carbonate	Company L		Metric tonnes/yr	Company AL	15000	Metric tonnes/yr	Process
Gypsum	Company F	11000	Metric tonnes/yr	Company A	10000	Metric tonnes/yr	Non-process
Gypsum	Company F	11000	Metric tonnes/yr	Company C	30000	Metric tonnes/yr	Process
Gypsum	Company F	11000	Metric tonnes/yr	Company AL	15000	Metric tonnes/yr	Process
Gypsum	Company F	11000	Metric tonnes/yr	Company AK	90	Metric tonnes/yr	Process
Gypsum	Company I	10000	Metric tonnes/yr	Company AL	15000	Metric tonnes/yr	Process
Gypsum	Company I	10000	Metric tonnes/yr	Company C	30000	Metric tonnes/yr	Process
Gypsum	Company I	10000	Metric tonnes/yr	Company AK	90	Metric tonnes/yr	Process
Gypsum	Company I	10000	Metric tonnes/yr	Company A	10000	Metric tonnes/yr	Non-process
Hydrochloric acid	Company H	8000	Metric tonnes/yr	Company D	4000	Metric tonnes/yr	Process
Hydrochloric acid	Company H	8000	Metric tonnes/yr	Company G	4000	Metric tonnes/yr	Process
Hydrochloric acid	Company H	8000	Metric tonnes/yr	Company Y	94.3	Metric tonnes/yr	Process
Lime	Company A	13	Metric tonnes/yr	Company F	70000	Metric tonnes/yr	Process
Lime	Company A	13	Metric tonnes/yr	Company AK	4500	Metric tonnes/yr	Process
Lime	Company A	13	Metric tonnes/yr	Company AL	70000	Metric tonnes/yr	Process
Lime	Company A	13	Metric tonnes/yr	Company AD	180	Metric tonnes/yr	Process
Lime	Company A	13	Metric tonnes/yr	Company H	18560	Metric tonnes/yr	Process
Off-spec product	Company O	3	Metric tonnes/yr	Company AC	250	Metric tonnes/yr	Process
RCU catalyst (Residue Cra	Company B	2680.424	Metric tonnes/yr	Company C	3000	Metric tonnes/yr	Process

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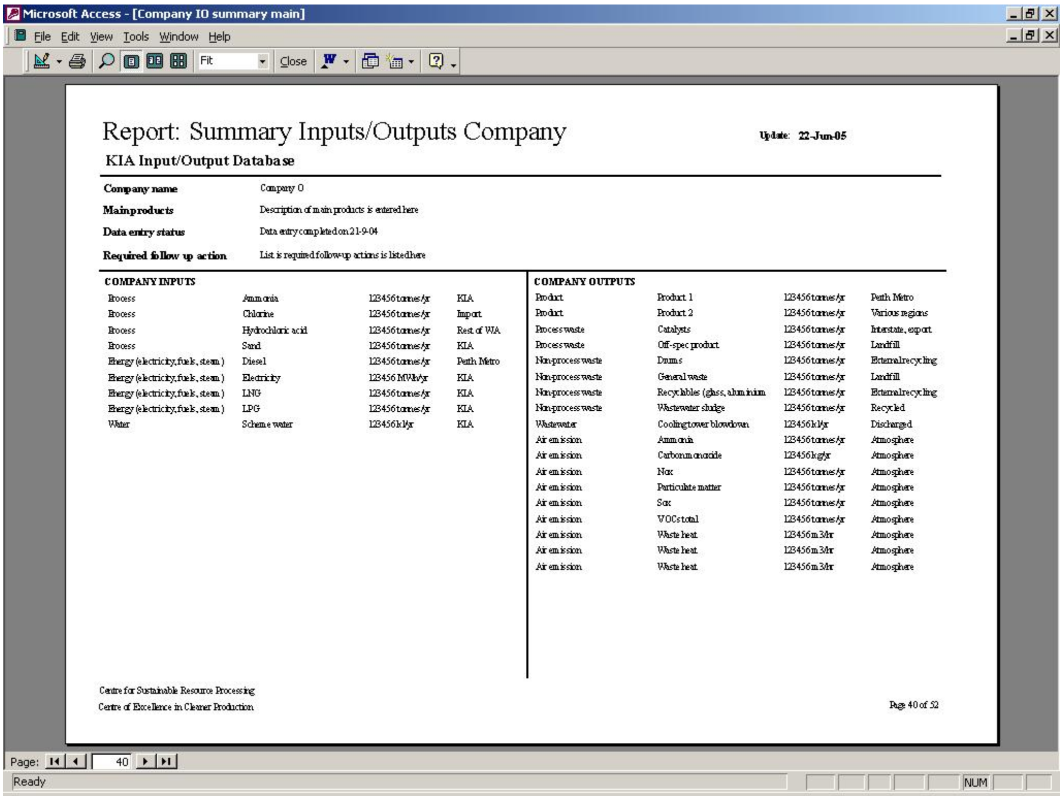
Figure: Example of Input/Output Match Report in Kwinana Database



Report: Summary Inputs/Outputs Company

Update: 22-Jun-05

KIA Input/Output Database

Company name	Company O
Main products	Description of main products is entered here
Data entry status	Data entry completed on 21-9-04
Required follow up action	List is required follow-up actions is listed here

COMPANY INPUTS

Process	Ammonia	123456 tonnes/yr	KIA
Process	Chlorine	123456 tonnes/yr	Import
Process	Hydrochloric acid	123456 tonnes/yr	Rest of WA
Process	Sand	123456 tonnes/yr	KIA
Energy (electricity, fuels, steam)	Diesel	123456 tonnes/yr	Perth Metro
Energy (electricity, fuels, steam)	Electricity	123456 MWh/yr	KIA
Energy (electricity, fuels, steam)	LNG	123456 tonnes/yr	KIA
Energy (electricity, fuels, steam)	LPG	123456 tonnes/yr	KIA
Water	Scheme water	123456 kl/yr	KIA

COMPANY OUTPUTS

Product	Product 1	123456 tonnes/yr	Perth Metro
Product	Product 2	123456 tonnes/yr	Various regions
Process waste	Catalysts	123456 tonnes/yr	Interstate, export
Process waste	Off-spec product	123456 tonnes/yr	Landfill
Non-process waste	Drums	123456 tonnes/yr	External recycling
Non-process waste	General waste	123456 tonnes/yr	Landfill
Non-process waste	Recyclables (glass, aluminium	123456 tonnes/yr	External recycling
Non-process waste	Wastewater sludge	123456 tonnes/yr	Recycled
Wastewater	Cooling tower blowdown	123456 kl/yr	Discharged
Air emission	Ammonia	123456 tonnes/yr	Atmosphere
Air emission	Carbon monoxide	123456 kg/yr	Atmosphere
Air emission	Nox	123456 tonnes/yr	Atmosphere
Air emission	Particulate matter	123456 tonnes/yr	Atmosphere
Air emission	Sox	123456 tonnes/yr	Atmosphere
Air emission	VOCs total	123456 tonnes/yr	Atmosphere
Air emission	Waste heat	123456 m3/hr	Atmosphere
Air emission	Waste heat	123456 m3/hr	Atmosphere
Air emission	Waste heat	123456 m3/hr	Atmosphere

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Figure: Example of Company Input/Output Report in Kwinana Database

APPENDIX 4: FORMULAS AND ASSUMPTIONS FOR PRELIMINARY TECHNICAL ASSESSMENTS – FLUE GASES (CHAPTER 8)

Technology	Formulas and Assumptions
Heat exchangers	Working liquid: § Assumption = water *Inlet temperature of working liquid:* § Assumption = 20^{o}C (293 K) *Flow rate working liquid [kg/s]:* § Estimate = sufficient to increase temperature of working liquid to approx 75% of inlet temperature of the flue gases *Specific heat water:* § 4.19 kJ/kg.^{o}C *Specific heat flue gas:* § Assumption = 1.25 kJ/kg.^{o}C *Heat transfer co-efficient:* § Assumption = 600 kJ/m^2-hr-^{o}C *Required heat transfer area [m^2]:* § Formula = recovered energy [kJ/hr] / (Delta temp flue gas in-out [^{o}C] * heat transfer co-efficient [kJ/m^2-hr-^{o}C]) *Recovered energy – heat content [TJ/yr]:* § Formula = recovery efficiency [%] * heat content flue gases [TJ/yr] *Recovered energy – temperature [^{o}C]:* § Formula = inlet temp working liquid [^{o}C] + recovered energy [kJ/sec] / (flow rate working liquid [kg/sec] * specific heat working liquid [kJ/kg.^{o}C]) *Required total capacity [MW]:* § Formula = (recovered energy [TJ/yr] * 1,000,000) / (7,000 operating hours / 3,600)
Waste heat boiler	*Inlet temperature of boiler feed water:* § Assumption = 20^{o}C (293 K) *Flow rate of boiler feed water [kg/s]:* § Estimate = sufficient that fossil fuel input is approx 25% of total heat content of inlet flue gases [TJ/yr] *Outlet temperature of steam:* § Assumption for on-site options = 300^{o}C (573 K) § Assumption for collaborative options = 400^{o}C (673 K) *Specific heat water:* § 4.19 kJ/kg.^{o}C *Specific heat flue gas:* § Assumption = 1.25 kJ/kg.^{o}C *Steam production [*TJ/yr*]:* § Formula = (flow rate boiler feedwater [kg/sec] * specific heat water [kJ/kg.^{o}C] * delta temperature boiler feed water in-out [^{o}C]) * 3600 * 7,000 operating hours per year / 10^9 *Steam production [ktonnes/yr]:* § Formula = flow rate boiler feedwater [kg/sec] * 3,600 * 7,000 operating hours per year / 10^9 *Flue gas input:* § Assumption = flue gases > 300^{o}C are preferred *Required total capacity [MW]:* § Formula = (recovered energy [TJ/yr] * 1,000,000) / (7,000 operating hours / 3,600)

Technology	Formulas and Assumptions
Economiser	*Working liquid:* § Assumption = water *Inlet temperature of working liquid:* § Assumption = 20°C (293 K) *Flow rate working liquid [kg/s]:* § Estimate = sufficient to increase temperature of working liquid to approx 75% of inlet temperature of the flue gases *Specific heat water:* § 4.19 kJ/kg.°C *Specific heat flue gas:* § Assumption = 1.25 kJ/kg.°C *Recovered energy – heat content [TJ/yr]:* § Formula = recovery efficiency [%] * heat content flue gases [TJ/yr] *Recovered energy – temperature [°C]:* § Formula = inlet temp boiler feed water [°C] + recovered energy [kJ/sec] / (flow rate boiler feed water [kg/sec] * specific heat water [kJ/kg.°C]) *Required total capacity [MW]:* § Formula = (recovered energy [TJ/yr] * 1,000,000) / (7,000 operating hours / 3,600)
Kalina cycle	*Electricity production [MWh/yr]:* § Formula = recovery efficiency [%] * heat content flue gases [TJ/yr] * 277.78 MWh/TJ *Thermal energy output [TJ/yr]:* § Assumption = thermal output only when inlet flue gas temperatures > 300°C § Formula = energy content flue gases [TJ/yr] * (100% - recovery efficiency Kalina cycle [%]) * efficiency heat exchanger [%] *Required total capacity [MW]:* § Formula = electricity production [MWh/yr] / 7,000 operating hours per year *Capacity of 1 unit [MW/unit]:* § Formula = average inlet temperature of flue gases [°C] * 28.257 - 2410.5[5] *Required number of units:* § Formula = required total capacity [MW] / capacity of 1 unit [MW]
Organic Rankine cycle	*Electricity production [MWh/yr]:* § Formula = recovery efficiency [%] * heat content flue gases [TJ/yr] * 277.78 MWh/TJ *Thermal energy output [TJ/yr]:* § Assumption = thermal output only when inlet flue gas temperatures > 300°C § Formula = energy content flue gases [TJ/yr] * (100% - recovery efficiency organic Rankine cycle [%]) * efficiency heat exchanger [%] *Required total capacity [MW]:* § Formula = electricity production [MWh/yr] / 7,000 operating hours per year *Capacity of 1 unit [MW/unit]:* § Formula = average inlet temperature of flue gases [°C] * 23.943 - 2056.2[6] *Required number of units:* § Formula = required total capacity [MW] / capacity of 1 unit [MW]

[5] Developed formula based on Valdimarsson P. and Eliasson L., 2003, Factors influencing the economics of the Kalina power cycle and situations of superior performance, International Geothermal Conference, Reykjavík.

Technology	Formulas and Assumptions
Conventional combined cycle	*Electricity production [MWh/yr]:* § Formula = recovery efficiency [%] * heat content flue gases [TJ/yr] * 277.78 MWh/TJ *Thermal energy output [TJ/yr]:* § Assumption = thermal output only when inlet flue gas temperatures > 300^{o}C § Formula = energy content flue gases [TJ/yr] * (100% - recovery efficiency conventional combined cycle [%]) * efficiency heat exchanger [%] *Required capacity [MW]:* § Formula = electricity production [MWh/yr] / 7,000 operating hours per year *Fossil fuel use [TJ/yr]:* § Assumption = fossil fuel use only required if flue gas temperatures < 300^{o}C § Formula = flow rate working liquid [kg/sec] * specific heat working liquid [kJ/kg.K] * (573 K - temperature flue gas [K])
Energy transportation in insulated pipes	*Outlet temperature [^{o}C]:* § Formula = inlet temp [^{o}C] * (100% - loss per 100m [%])$^{\text{distance [100m]}}$ *Outlet heat content [TJ/yr]:* § Formula = inlet heat content [TJ/yr] * (100% - loss per 100m [%])$^{\text{distance [100m]}}$

[6] Developed formula based on Obernberger I., Thonhofer P. and Reisenhofer E. 2002 Description and elevation of the new 1,000 kW organic Rankine cycle process integrated in the biomass CHP plant in Lienz, Austria, Euroheat & Power, Vol. 10.