Fostering Industrial Symbiosis for Regional Sustainable Development Outcomes

Steve Harris[1*], Rene van Berkel,[2] and Biji Kurup[1]

1. Centre of Excellence in Cleaner Production, Curtin University of Technology, GPO Box U1987 Perth WA, 6845, Australia
2. Centre for Sustainable Resource Processing/CSIRO Minerals, PO Box 1130. Bentley, WA, 6102, Australia

Abstract

Industrial symbiosis has shown strong potential to contribute to sustainable development, but efforts to purposely foster initiatives have met with mixed success. Preliminary research of industrial symbiosis in the Kwinana Industrial Area (Western Australia) identified three enabling mechanisms that could potentially enhance symbiosis: facilitating structures (ways to increase information sharing and collaboration), operational and contractual arrangements (ways for companies to share the risks and benefits) and evaluation tools (methods to track and quantify the sustainability benefits of industrial symbiosis). A global review of 22 industrial symbiosis examples in heavy industrial areas (covering North America, Europe, Asia and Australia) has since been completed. The paper presents the lessons on the implementation of industrial symbiosis initiatives (with regard to the role of the three enabling mechanisms) and their contribution to sustainable development (in terms of the triple bottom line).

The available quantitative information on industrial symbiosis benefits was found to be inconsistent and patchy, but demonstrates that benefits can be substantial. A supplementary qualitative analysis (based on 20 attributes of industrial symbiosis relevant to sustainable outcomes at the regional level) shows that sustainability value creation is most evident at the project level. In comparison, benefits at the network level occur through potential improvements in regulatory frameworks and continuous learning of best practice. Finally, the paper discusses and presents how findings on the three enabling mechanisms are being expanded in the next stage of research, to develop a model aimed at enhancing industrial symbiosis.

1. Introduction

Industrial symbiosis (IS) is a practical application of the emerging discipline of industrial ecology. Whilst industrial ecology concerns the resource flows of society and integrity of ecological systems, IS focuses on flows of resources (by-products, energy, water and potentially even human resources) between companies. It can most simply be described as the "waste=food" concept, with 'symbiosis' originating from biological ecology and referring to mutual (in most cases) benefit as in nature where nothing is wasted. Chertow (2000) provides the most commonly quoted definition: "*Industrial symbiosis engages*

* Corresponding author. Tel: +61892661310. E-mail address:S.Harris@curtin.edu.au

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". Industrial symbiosis can be viewed as the *process* that leads to an industrial ecosystem (i.e. a network of exchanges) as the *outcome* (van Berkel, 2006). The related term "regional resource synergies" is concerned with physical exchanges of natural resource flows between different businesses or with other sectors to achieve more productive use of the materials, energy or water contained in the resource flows exchanged (Bossilkov et al, 2006).

On first appearance the application of IS can offer several benefits to the companies involved and make a significant contribution to sustainable development. It is intuitive that the utilisation of a previously unused (e.g. in the case of released steam) or discarded (e.g. sludge to landfill) resource can typically offer financial savings to both the utilising company and the provider, whilst reducing the use of raw materials, energy or water, and avoiding disposal to landfill. Social benefits may include job creation, reduction of emissions (e.g. gaseous pollution or dust), or aesthetic improvements (e.g. reduction of waste piles). Whilst some sustainability benefits have been reported in the literature (most notably for Kalundborg, Denmark – the exemplary example of IS (Jacobsen, 2003)) the contribution of IS to sustainable development has not been extensively covered.

Similarly, the methodologies and processes involved in the actual fostering and implementation of IS exchanges and regional IS initiatives (or networks) has had limited attention. Typically the intricacies of the process, the importance of human interaction and the complexity of company interaction are underestimated. A few methodologies have been reported such as By-Product Synergy (Mangan, 1998) or the Eco-Industrial Handbook (Lowe, 2001) but the majority of examples appear to have been implemented by consultants or personnel of local councils with little previous experience in IS and with little reference material to consult.

The research on which this paper is based was primarily initiated to investigate in detail the potential and actual contribution of collaborative approaches, such as regional resource synergies, industrial symbiosis and/or industrial ecology, for sustainable development at the regional level in heavy industrial areas, in particular the Kwinana Industrial Area in Western Australia. It was conceived that this project would learn from national and international best practices, investigate the barriers and incentives and propose innovative ways for achieving regional resource synergies. The first phase of the project (on which this paper reports) was a baseline assessment of global best practice examples which examined the implementation of industrial symbiosis initiatives and the contribution to sustainable development (van Berkel 2006).

Despite its compelling logic, IS developments face a range of challenges. In the context of this research, three were singled out, namely: (1) sharing of information on material, energy, water and other resource flows between different operators in the same industrial area; (2) establishing operational and contractual arrangements to secure management skills, technical know how and finances for the implementation of IS projects; and (3) estimating the environmental, social and economic benefits (triple bottom line) of resource exchange networks. The project hypothesis is therefore that greater application of industrial symbiosis can be achieved through, the following three '*enabling mechanisms'* (van Berkel 2006):

- *Facilitating structures* that encourage collaboration among industries (and other sectors) operating in the same industrial area.

- *Operational and contractual arrangements* that enable commitment of the necessary resources for implementation of IS projects.

- *Evaluation methods* that can track and quantify the environmental, social and economic benefits (triple bottom line) of IS projects.

The relationship between these enabling mechanisms and the regional synergy development process is depicted in Figure 1.1. Although the research is primarily designed to serve and support the identification and evaluation of IS in Kwinana, opportunities to support similar processes in other industrial areas in Australia (including in particular in Gladstone, Queensland) are also being pursued (van Berkel et al, 2006; Corder et al, 2006).

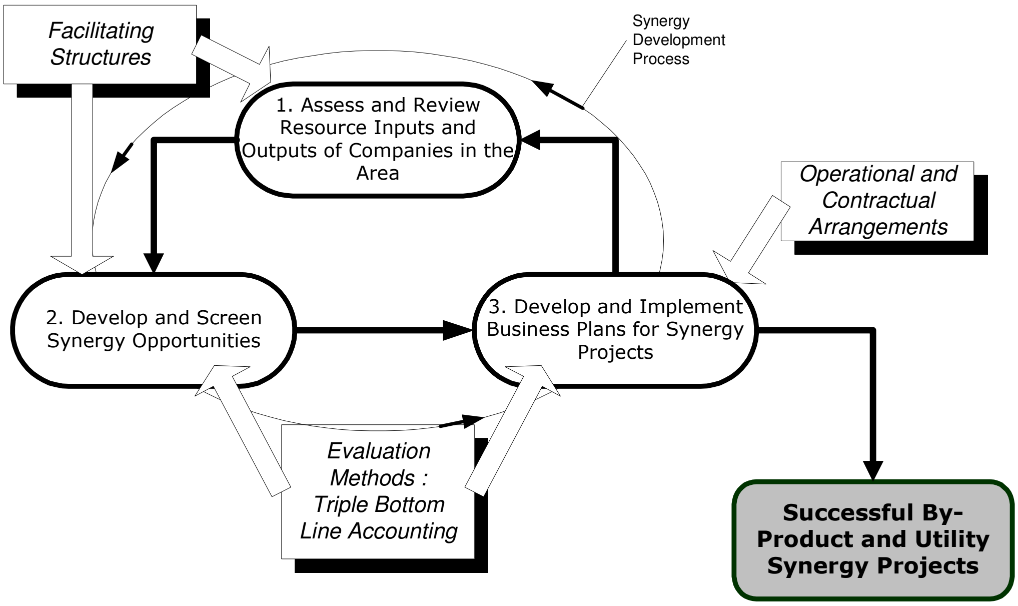


Figure 1.1: Contributions of enabling mechanisms to the process for development, evaluation and implementation of IS. (source: van Berkel, 2006)

This paper begins with a description of the methodology used for the best practice global review of industrial symbiosis networks/regional resource synergy examples. It then discusses the lessons from the findings with regard to the three enabling mechanisms. Next the lessons on the contribution of industrial symbiosis to sustainable development are presented and finally the paper discusses how these lessons are being built on in the next phase of the research project.

2. Global Review of Industrial Symbiosis

The best practice review adopted a two-stage case study methodology (van Berkel, 2006). In the first stage a comprehensive case study was developed for each of the short-listed heavy industrial areas. For each industrial area studied, the case study aimed to cover the roots of the IS initiative in the study area, the level of participation of industry and other stakeholders, the synergy development initiatives undertaken, as well as practical synergy projects implemented and/or 'being pursued' along with their environmental, social and economic outcomes. In the second stage, the collection of case studies was reviewed to identify common elements, draw conclusions regarding actual and potential contributions to sustainable development and extract lessons with regard to the IS development process.

An extensive literature search was conducted to identify and select case studies for this best practice review. The sources consulted included scholarly, professional and industry journals, conference proceeding, publicly available research and consultancy reports, local and state government reports as well as web-based case studies and reference documents. This search identified 61 regions from which 22 regions were selected for further analysis (based on the perceived availability of information, relevance for heavy industrial areas, involvement of minerals, metals, chemicals and/or other heavy industries and geography). The regions included in this best practice review cover four continents, respectively (van Berkel 2006):

- ***Asia*****:** Daedeok Technovalley (Korea), Jurong Island (Singapore), Kawasaki (Japan), Map Ta Put (Thailand), Naroda Industrial Estate (India), Taiwan and Zaozhuang (P.R. of China)
- ***Australia*****:** Kwinana (WA) and Gladstone (Qld).
- ***Europe*****:** Forth Valley and Humberside (both UK), Rotterdam Harbour and Industry Complex and Moerdijk (both The Netherlands), Kalundborg (Denmark) and Heidelberg/Rhine Neckar Triangle (Germany)
- ***North America***: New Jersey Chemical Industry Project, Fairfield Ecological Business Park (Baltimore), Londonderry (New Hampshire), (North) Texas Project (all USA), Alberta Industrial Heartland, Sarnia Lambton (both Canada) and Tampico (Mexico)

Both primary and secondary data was collected for the 22 case studies, preferably from multiple stakeholders in each of the case study regions. The secondary data were extracted from literature, websites and other public information sources, and was used to compile a preliminary case study for the region. A considerable effort was then made to extend and deepen each case study through primary data collection. An open questionnaire was prepared and circulated to key contacts that could be established in each region. The questionnaire addressed the:

- history of the IS developments,
- IS projects in place,
- social, environmental and economic outcomes,
- operational and contractual arrangements in place for these synergy projects,
- IS development activities undertaken (van Berkel, 2006).

It soon turned out that this level of detailed information did not exist for the international case studies, and hence to acquire experience and expertise from key individuals in each of the regions, telephone interviews (international regions) and one-on-one consultations (Australian regions) were conducted. The data sources on which the case studies are grounded are therefore at best incomplete and in some regions remained patchy even after repeated follow up efforts.

3. Lessons on Implementation

3.1 Comparative Analysis

From the 22 case study regions 162 ‘icon’ synergies[1] were identified (van Berkel 2006). Thirteen regions (60 percent of the regions) had 5 or less synergy projects, having in total 41 synergy projects (15 per cent of the synergy projects). Only three regions (Fairfield, Daedeok and Jurong Island, 14 per cent of the regions) did not achieve any icon synergy project. Overall the set of 162 synergy projects is dominated by icon projects from just four regions, namely: Forth Valley (UK), Kalundborg (Denmark), Map Ta Phut (Thailand) and Kwinana (Australia). These four regions (18 per cent of the regions) have each at least 17 synergy projects and in total 76 synergy projects (47 per cent of all synergy projects). The IS initiatives in these four ‘hot spot’ regions are summarised in Box 3.1. Overall, there is strong support that IS projects are *achievable* as over 85 per cent of the regions studied succeeded in implementing synergy projects.

A further analysis of the icon synergy projects revealed that the current experience is still limited to comparatively straightforward resource synergies (van Berkel 2006). This is evidenced by the breakdown of the synergy projects in terms of the resource exchanged and the business relationships established (see Figure 3.1).

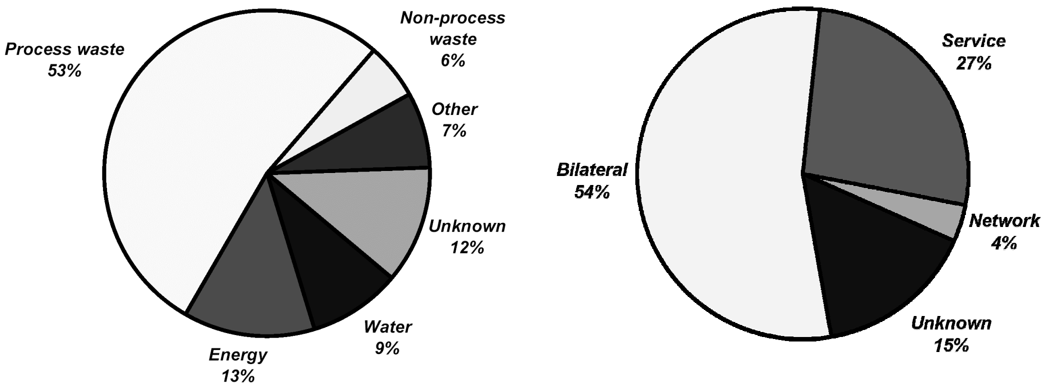


Figure 3.1: Synergy projects by type of resource exchanged (left) and by business relationship (right) (n = 162) (source Van Berkel 2006).

Just over half of the successful synergy projects are based on the use of a process by-product by another company, with another quarter involving shared use of water and/or energy utilities. Likewise just over half of the synergy projects is governed by a bilateral contractual arrangement between a source and sink company (in some cases involving a third party to process and transfer the resource flow). Another quarter of the synergy projects is set up as a service provider arrangement, where one organisation provides a service to several customers, for example a water or energy utility or a waste management or recycling service.

[1] We use the term ‘icon’ synergies to refer to those that were judged to be exemplary IS examples and not considered normal supply synergies.

Forth Valley (Scotland, UK)
Incorporating Grangemouth, the largest industrial area of Scotland, the region includes four large power stations, a cement works, three petrochemical sites, and two paper mills. A PhD study revealed 26 existing synergies and 16 potential synergies (Harris, 2004; Harris, forthcoming). Existing synergies include: energy recovery from 54,000 tonnes of sewage sludge producing enough electricity to power 30,000 homes; ScotAsh recovers and reuses nearly 500,000 tonnes per annum of ash from a power station which is utilised in cement, concrete addition, waste stabilisation and land rehabilitation; LaFarge cement works utilises recycled liquid fuel and scrap tyres for fuel, and recycled glass/sand as alternative raw materials. Industrial symbiosis in the region is now being driven by the Scottish Industrial Symbiosis Programme, part of a UK national programme that recently received £13 million from the UK government (DEFRA, 2005).

Kalundborg (Denmark)
The quintessential example of industrial symbiosis developed organically over a period of 25 years. At the heart of the network of exchanges is Asnaes power station which supplies power and district heating to the city of Kalundborg and process steam to Statoil refinery and Novo Nordisk. Fly-ash from Asnaes is used for cement making, and nickel and vanadium are recovered from the ash, whilst gypsum from the desulphurisation of the flue gas is supplied to Gyproc for construction materials. Statoil send wastewater to Asnaes for reuse, some of which is returned as steam. Novo Nordisk supply by-product yeast slurry from insulin production for pig fodder, and Novozymes provide by-product biomass by pipeline to farmers for replacement fertiliser. The system of exchanges developed because of the openness, close cooperation and mutual trust that existed in the relatively tight knit business community (Jacobsen, 2003).

Kwinana (WA, Australia)
The Kwinana Industrial Area is the largest industrial site in Western Australia consisting of approximately 120 km^2 and responsible for more than A$4.3 billion of annual economic output (Sinclair-Knight-Merz, 2002). The area is dominated by heavy process industries and supported by the Kwinana Industries Council (KIC). Following a study that examined material and energy flows within the region, KIC initiated the Kwinana Industries Synergies Project. A comprehensive research program conducted at Curtin University of Technology supports the development of further synergies (Bossilkov et al, 2005; van Berkel, 2006). An inventory of existing synergies at Kwinana showed that there are 47 synergy projects in place, placing the region as a leading example of industrial symbiosis (van Beers et al, 2005). Synergies include: CSBP chemical plant sending gypsum and CO_2 to Alcoa alumina refinery for residue area amelioration; a water reclamation plant produces 6 GL/yr of premium industrial process water from tertiary wastewater; and the HISmelt pig iron making plant that avoids coke ovens, saves 20% CO_2 emissions and can utilise local by-products including lime kiln dust, treated wastewater and iron ore fines.

Map Ta Phut (Thailand)
The Map Ta Phut is the largest in industrial estate in the Rayong Province and was established in 1985. It was reserved for the petrochemical industry and its downstream processes, and houses 89 factories with 11,500 employees (GTZ/IEAT, 2001). The local Industrial Estate Authority of Thailand (IEAT) provides the management platform to identify and realise industrial symbiosis opportunities. There are currently seventeen examples of industrial symbiosis including (GTZ/IEAT, 2001): five cogeneration plants supplying electricity and steam to the petrochemical industry; waste solvents recycled through distillation; waste oil used as an alternative fuel for cement kilns; ferrous chloride and hydrochloric acid are collected (~640,000 tonne/yr) and used in ferric chloride production.

Box 3.1: Summary of Industrial Symbiosis 'hot spot' regions

3.2 Enabling Mechanisms[2]

The development of the IS initiatives was reviewed to gain a better appreciation of the barriers and incentives encountered when attempting to implement IS. As a general observation, it appeared that the complexity of the development, evaluation and implementation of IS is routinely overlooked. Synergies are identified once there is trust and mutual recognition and appreciation, which each require vision, leadership, dedication and a longer term perspective to develop and mature.

The review findings are presented here in the context of the proposed novel enabling mechanisms. As per the project hypothesis (see Section 1) enabling mechanisms cover *facilitating structures* (to foster collaboration among industries and other sectors operating in the same industrial area); *operational and contractual arrangements* (that enable commitment of the necessary resources for the implementation of IS projects) and *evaluation methods* (that can track and quantify the environmental, social and economic benefits (triple-bottom-line) of IS projects). The following picture emerged with regard to each of these enabling mechanisms.

1. *Facilitating Structures*: there is a strong indication that an approach based on industry facilitation and provision of technical assistance might be up to four times more effective in achieving IS than an eco-industrial planning approach. Key ingredients for effective facilitation appear to be:

   - *Industry Leadership*: either one or a few of the leading businesses in the area and/or the local industry association, preferably takes the lead for the IS initiative (present in 65 per cent of the regions), potentially supported by either local/regional government or state/national government (each achieved in around 1/3 of the regions studied).

   - *Process Management*: day-to-day coordination of the regional synergy development initiatives is best done through a hands-on working committee comprising of representatives of key businesses and facilitator(s) and consultant(s) providing input to the synergy development process (achieved in some 65 per cent of the regions). The synergy development process appears to benefit from the creation of a high level steering or advisory group (existent in 73 per cent of the regions studied), comprising of business leaders, government representatives and potentially others (community, industry representatives from other regions, etc.).

   - *Synergy Development Activities*: there is a strong link between three of the synergy development activities, namely collection of process input/output data, third party identification of synergy opportunities and synergy development workshops. The absence of any of these three synergy development activities in four regions coincided with the fact that these four regions did not succeed in identifying any new synergy opportunities.

   - *Funding*: provisions need to be made to cover the costs for data collection, synergy opportunity identification and screening, and industry facilitation. However it is not usually necessary to provide financial support for the actual investment costs for the

[2] This section is reproduced here directly from section 3.5.2 of van Berkel (2006).

implementation of any particular synergy project. Except for Jurong Island (for which no detailed data are available), government at least part funded the development activity in all regions. In 12 regions (55 per cent of regions) industry appears to have made a contribution to the funding of the synergy development effort. This includes all European and all Australian regions.

- *Promotion*: it is generally beneficial to document and communicate regional synergy achievements to various stakeholders, including local industries (to enhance their participation), community and other stakeholder groupings (to inform them of, and engage them in, local industry sustainability initiatives) and government (including policy makers, regulators etc, to raise awareness for synergy achievements and help establish a collaborative attitude among government representatives). It is routinely undertaken in at least 18 regions (82 per cent), with uncertainty about the presence of promotional activities for the remaining four regions. Periodic newsletters and likewise publications dominate (provided in 16 regions) in the communications, followed by awareness workshops (provided in 10 regions), website (in 8 regions), case studies (in 7 regions) and others (in 5 regions).

2. *Operational and Contractual Arrangements*: need to be considered in the context of the specific risks and opportunities of a particular synergy project. Five key determinants emerged that can provide a basis for the consideration of best practice operational and contractual arrangements. These are:

   - *Ownership* (project assets): who makes the investment and ultimately owns the project assets for capturing the resource in the source process, for processing and transferring this to the use process, and for feeding it into the use process.

   - *Ownership and Liabilities* (traded resource): who assumes ownership and formal liability for the application of the recovered materials, in particular in regards to the materials performance (failure of the recovered material to achieve and maintain product specifications) and environmental risks (potential future environmental contamination from the reused by-products as a result of leaching or other processes).

   - *Supply Risks* (availability of critical process input): how the company receiving a by-product or utility from another company as critical input for its own processes, can prepare itself for a situation where the other company fails to deliver on its supply obligations for the by-product or utility.

   - *Demand Risks* (utilisation of the recovered by-product or utility generated): how the company making the investment in the synergy project can cover itself in case demand from its customers is lower than projected.

   - *Price* (value of the exchanged resource for each of the synergy partners): will largely be driven by the value of the recovered material (i.e. how valuable is the recovered material to the user, compared to supply of traditional inputs), by the avoided disposal costs (i.e. how expensive would it otherwise be for the source company to dispose of the material in an acceptable manner), and the costs of handling, transfer and processing of the material (i.e. the costs of turning the by-product from the source company to the use company in a manner that it can feed into its processes).

3. *Evaluation methods* (triple bottom line accounting method). Information on sustainability benefits of the regional synergy projects was patchy and incomplete, as the combined result of the non-existence of a standardised methodology, the non-existence of the underpinning data, and the (perceived and/or actual) commercial sensitivity of data. A profound opportunity therefore remains to boost interest in IS by having available a consistent and transparent methodology for tracking economic, environmental and social benefits from IS initiatives.

4. Contribution to Sustainable Development

Having confirmed that IS projects are *achievable*, an attempt was made to assess the nature and size of the sustainability benefits accomplished in the case study regions. As discussed above, the reported benefits of industrial symbiosis projects in the literature have typically been limited to cost savings and emission reductions. There has been little attempt to assess the full, wider benefits of IS such as social and environmental opportunities for the exchange partners or local community/region. In addition there is no method to assess future projects, which would ideally require a life cycle approach. Therefore an approach was developed to evaluate the benefits of industrial symbiosis across the life cycle of the project (Kurup et al, 2005). To illustrate the methodology we examine a case study example from the Kwinana region (Western Australia).

In 1998 a joint study (Kwinana Water Link study) between the Water Corporation, Kwinana industry and government on the future water demand of industry predicted a 84% rise in water reuse by 2007, on 1997 quantities (Adison, 2004). The Water Corporation therefore developed the Kwinana Water Reclamation Plant (KWRP), to reuse secondary treated effluent from a nearby wastewater treatment facility. A micro filtration/reverse osmosis unit (built at a cost of A$ 25 million), produces a low TDS (Total Dissolved Solids) water supply for use by local industries including CSBP, Tiwest, Kwinana Cogeneration Plant, BP and HIsmelt. The new supply replaces 6 GL/year of scheme water and the low TDS enables the process plants to cut their use of chemicals in cooling towers and other process applications; thereby reducing metal loads in their effluents. In addition, the companies are now able to discharge their treated effluents into the deep ocean outfall through the Water Corporation pipeline, instead of the adjacent Cockburn Sound, a sensitive marine environment (Water Corporation, 2003).

Using this case study, Table 4.1 illustrates the developed methodology and the triple bottom line (TBL) costs and benefits across the life cycle of the project. It compares the previous situation with the building of KWRP and demonstrates that there can be a large range of benefits across the life cycle of an IS project. This method is currently under further development, and would most likely be useful in cases where the evaluation of the business case alone, does not provide satisfactory evidence for project implementation (Kurup et al, 2005).

Life Cycle Stage	**Environmental**	**Score**	**Social**	**Score**	**Economic**	**Score**
Planning and Design (1998-2002)	Material & energy use and impacts from pilot tests.	-	New skills developed for planning and designing of the water reclamation plant. Community commitment in planning.	+ +	Wages for planning & designing team. Generate business for local suppliers. Capital investment.	+ + -
Construction (2003-2004)	Land for plant and infrastructure. Material & energy use for plant and pipe infrastructure.	- --	Job creation as construction and manufacture of supplies. Skill enhancement as the result of a new technology.	++ +	Wages for construction workers. Generate business for local suppliers. Tax generated from wages paid. Capital investment.	++ ++ + --
Operation (Nov 2004 +)	Scheme water conservation. Water quality and eco-system improvement in coastal zone. Energy use and GHG emission. Chemical use.	+++ +++ - --	Improved recreational value of coastal zone and reduced health risks to community. Job creation and security. *	++ ++	Water security for industry users. Better opportunities for tourism and aquaculture in coastal zone. Tax generation. High grade water for industry. Increased water cost for industry.	++ ++ + + +
Refurbishment Every 5 years[28]	Waste from refurbishment. Material and energy use for refurbishment.	- -	Maintain water security. Job creation (temporarily).	+++ +	Wages. Generate business for local suppliers. Capital investment.	+ + -
Decommission (2029)	Land reclamation. Recycling of material. Waste from decommissioning.	+ + -	Temporary job creation. Permanent job loss. Loss of water security.	+ -- ---	Wages from temporary employment. Loss of business for local suppliers. Value from recycled material.	- + -

--- major negative, -- negative, - minor negative, 0 neutral (may involve a shift in impact ie. a shift of jobs from mining to recycling), + minor positive, ++ positive, +++ major positive
GHG: green house gas
+Efficient technology compared to 20 years ago which is 30% cheaper now and could be considered an economic benefit (Walker, 2003)
* Job creation and security will principally be because of industries using the KWRP water, together with increased tourism and aquaculture in waters of coastal zone and not the plant itself which will be fully automated.

Table 4.1: Life cycle economic, social and environmental implication of KWRP (25years) (source: Kurup et al, 2005)

A limited amount of quantitative information was available for 13 of the case study regions (60 per cent of the regions) and Table 4.2 provides a summary (van Berkel 2006). Most of the information deals with one or a few icon synergy projects in the region. This is most likely biased for the 'big ticket' synergies in the respective region. Total benefit information is only available for the Humber, Moerdijk and Kalundborg regions. The quantitative information is biased for environmental information, mostly pertaining to diversion of waste materials from landfill and equivalent energy savings.

Even though the reported environmental and financial benefits (as in Table 4.2) are impressive, the overall picture of the sustainability benefits from the IS projects remains patchy and inconsistent (van Berkel 2006). This relates both to the individual synergy projects considered or implemented, as well as the total impact of all synergy projects in a given region.

Despite the lack of quantitative detail there is a general consensus from the case studies that each of the implemented IS projects had an acceptable business case. In most projects there appears to be a combination of traditional business case elements (i.e. direct savings of operational costs or increases in operational revenues) with less tangible business case elements (i.e. costs of regulatory compliance, long term impact on government and community relationships, and the license to operate). There is also evidence in some projects that environmental market based instruments tilted the project economics in favour of implementation. For example, the City Council in Rotterdam (Netherlands) provided a guarantee to back the district heating investment for waste heat recovery. In Humberside (UK) a utility company achieved an exemption from carbon tax for its investment in the combined heat and power station. It may thus be concluded that the businesses that pursued IS projects attempted to improve their business while simultaneously improving environmental, and to a lesser extent, social performance (van Berkel, 2006).

Given these difficulties in quantifying the sustainability outcomes from IS projects, an alternative approach was taken to illustrate how the development and implementation of IS contributes to sustainable development in and around heavy industrial areas. This focuses on the ways regional synergy development can lead to sustainability at the local level, or, in other words, the drivers behind more sustainable outcomes. The framework proposed for the assessment of mining and minerals processing operations is being used for this purpose. It was developed under the North American component of the global Mining, Minerals and Sustainable Development Project (IISD 2002). The seven headline sustainability criteria, originally captured as leading '*questions*', were expanded to 20 value elements relevant to IS projects. Each value element captures an aspect of IS projects that can lead to more sustainable outcomes

Region	Reported Sustainability Benefits		
	Environmental	Social	Economic
Forth Valley (UK)	▪ 54,000 tpa sewage sludge diverted from landfill ▪ 500,000 tpa fly-ash diverted from landfill ▪ 42,000 tpa tyres and RLF diverted from disposal and substituting for 40,000 tpa coal ▪ 11,000 tpa poultry litter diverted from disposal and generating 81GWh/yr renewable power	No information available	▪ £1.2 million/yr profit from fly-ash reuse
Humberside (UK)	▪ 183,000 tpa waste material diverted from landfill	▪ Saved 87 jobs ▪ Potential for 960 direct jobs and 1,440 indirect jobs	▪ £ 800 million/yr increase in economic activity
Kalundborg (DK)	▪ 2.1 million tpa potable water replaced by surface water ▪ Energy savings equivalent to 30,000 tpa coal and 19,000 tpa oil ▪ Some 280,000 tpa waste diverted from landfill (fly-ash, scrubber sludge etc) ▪ Replaced 200,000 tpa gypsum use and 2,800 tpa sulphur use	No information available	▪ Total investment U$ 75 million ▪ Total annual savings U$ 15 million ▪ Accumulated savings U$ 160 million
Moerdijk (NL)	▪ 85,000 tpa CO2 recovered ▪ 3.4 million tonne/yr steam recovery ▪ 0.5 GL/r water reuse	No information available	No information available
Rotterdam (NL)	▪ 6 MW waste heat recovery for district heating	No information available	No information available
Fairfield (USA)		No information available	▪ U$ 62 million investment in redevelopment of industrial facilities (incl. soil remediation)
Londonderry (USA)	▪ 18 ML/day reuse of treated waste water as cooling water	No information available	No information available
Sarnia Lambton (CAN)	▪ Some 175,000 tpa FGD gypsum diverted from landfill	No information available	No information available
Texas (USA)	▪ Energy savings equivalent to 78,000 tpa coal use ▪ 250,000 tpa waste diverted from landfill (shredder residue and slags) ▪ 18,000 tpa non ferrous metals recovered	No information available	No information available

Region	Reported Sustainability Benefits		
	Environmental	**Social**	**Economic**
Kawasaki (JAP)	▪ 30,000 tpa waste plastics used as blast furnace reductant ▪ 360 tpd waste plastics gasified for ammonia production	No information available	No information available
Map Ta Phut (Thailand)	▪ 80 tpa solvent recovered ▪ 11,800 tpa waste oil reused as fuel and/or for oil paints ▪ 20,000 tpa scale, dust and refractory material used as cement raw material ▪ 640,000 tpa ferrous chloride/hydrochloric acid recovered	No information available	No information available
Gladstone (AUS)	▪ 6.5 ML scheme water replaced by treated waste water	No information available	No information available
Kwinana (AUS)	▪ 10,000 tpa byproduct gypsum recovered for reuse ▪ 170,000 tpa CO2-eq emission reduction from one cogeneration plant ▪ 6 GL high grade industrial water recovered from treated waste water	No information available	▪ Investment in water reclamation plant A$ 29 million ▪ 20% premium price on reclaimed water

Table 4.2: Sustainability benefits reported in case study regions (source: van Berkel, 2006)

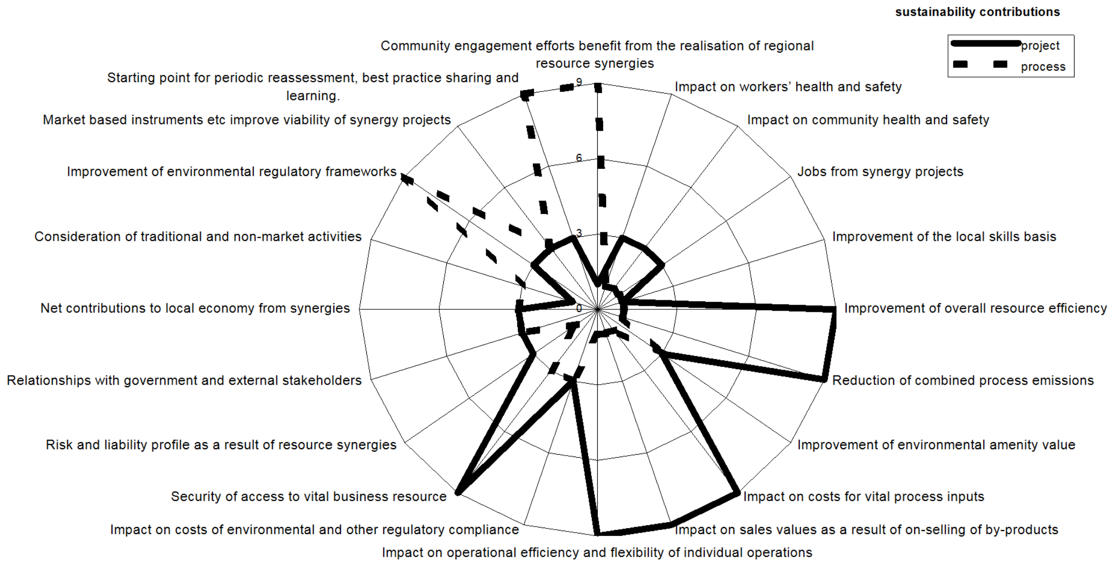
Headline Sustainability Criteria	Sustainability Value through IS projects	Kwinana Examples
1. **Engagement**: are engagement processes in place and working effectively?	1. Community engagement efforts can benefit from the platforms and processes established for the realisation of IS projects	The commitment to regional synergy developments supports the building of a positive image for business' commitment and efforts to improve sustainability and co-existence of industry and community in the Kwinana area.
2. **People:** will people's wellbeing be maintained or improved?	2. Impact on workers' health and safety	The achievement of health and safety benefits has in some cases benefited from regional synergies, albeit most likely not been critical or conditional. For example, availability of a use option for silica dust from fused alumina production contributes to meeting the costs of dust extraction and collection, which reduces occupational exposure.
	3. Impact on community health and safety	Recovery of lime kiln dust, and subsequent reuse as lime alternative, greatly reduced dust emissions compared to past practice of land filling.
	4. Job retention and/or creation from synergy project implementation and operation	Jobs created in the construction and operation of the synergy projects, for example the cogeneration plants.
	5. Improvement and strengthening of the local skills basis	Synergy projects have brought new technologies and skills to the region, for example co-generation and advanced water reclamation technologies
3. **Environment:** is the integrity of the environment assured over the long term?	6. Improvement of overall resource efficiency (energy, water, materials)	Injection of treated waste water from Kwinana waste water treatment plant upstream from bore field of alumina refinery achieves water reuse and reduces total water requirement
	7. Reduction of total environmental stress from process emissions	Combined stripping of nutrients from fertiliser works waste water and carbon from oil refinery waste water in artificial wetland reduces overall process emissions
	8. Improvement of environmental amenity value	Reuse of by-product gypsum from chemicals works in bauxite residue disposal improves plant growth and enhances rehabilitation of residue area
4. **Economy**: is the economic viability of the project or operation assured and will the economy of the community and beyond be better of as a result?	9. Impact on costs for vital process inputs (including energy, water and materials)	Lime kiln dust from cement company is now used as a lower cost replacement for lime for desulphurisation processes at pigment and pig iron plants
	10. Impact on sales values as a result of on-selling of by-products	Oil refinery sells elemental sulphur extracted from oil to nickel smelter
	11. Impact on operational efficiency and flexibility of individual operations	Cogeneration plant supplies process steam with greater availability and flexibility, which enables the oil refinery achieving higher overall efficiencies
	12. Impact on costs of environmental and other regulatory compliance	Cost of mandatory treatment of leachate from fly-ash pond is partly offset by on-selling of demineralised water to chemical works

Headline Sustainability Criteria	Sustainability Value through IS projects	Kwinana Examples
	13. Improvement in medium and long term security of access to vital business resource (e.g. land, ore, water etc)	Customers of the Kwinana Water Reclamation Plant benefit from the diversification of their water supply options, recognising increasing pressure on traditional water supplies
	14. Impact on company risk and liability profile as a result of resource synergies	Uncertainty in long term liability for reuse of bauxite residue applications for improvement of agricultural soils, resulted in alumina refinery terminating its involvement in this synergy project
	15. Benefit from improved relationships with government and external stakeholders	There is a perception among some of the most involved companies that their achievements in regional synergies has eased the way for achieving regulatory approvals for growth projects
	16. Impact on net contributions to local economy as a result of synergy project implementation and operation	The use of gypsum by-product from the chemical works in soil conditioning products aims to improve agricultural productivity in the region, in addition to direct jobs associated with recovery, processing and distribution of the gypsum product.
5. **Traditional and Non-Market Activities**: are traditional and non-market activities in the community and surrounding area accounted for in a way that is acceptable to the local people?	17. Providing a conducive environment for consideration of traditional and non-market activities	Over the years, companies have demonstrated a greater appreciation for the recreational value of the Cockburn Sound, and this has influenced the set up of the Kwinana Water Reclamation Plant to achieve not only water efficiency but also end the discharges of treated industrial effluents into the Cockburn Sound.
6. **Institutional Arrangements and Governance**: are rules, incentives, programs and capacities in place to address project or operational consequences?	18. Review of environmental regulatory frameworks to cater better for by-product synergies	Fly-ash is classified as controlled waste and the associated regulatory requirements add substantially to the costs of its recovery and reuse in construction materials
	19. Market based instruments and other incentives (e.g. waste levies, green tax breaks, etc) can improve the viability of synergy project investments	Potential for future greenhouse gas credits is additional benefit from investment in bauxite residue carbonation using process carbon dioxide from chemical works
7. **Synthesis and Continuous Learning**: does a full synthesis show that the net results will be positive or negative in the long term, and will there be periodic re-assessments?	20. The platforms and processes established for the development and implementation of synergy projects provide a starting point for periodic reassessment, best practice sharing and learning.	The committee structure set up in the Kwinana Industries Council to foster synergy developments has provided opportunities for sharing of best practices in other environmental and sustainability areas (e.g. with regard to company internal water and energy efficiency initiatives and tools.

Table 4.3: Contributions of industrial symbiosis initiatives to sustainability (source: van Berkel, 2006)

The 20 sustainability value elements from IS developments are summarised in Table 4.3 (middle column) along with an illustration from the Kwinana Industrial Area[3] (right hand column) (van Berkel 2006). The level of detail is largest in regard to the three dimensions of sustainability performance, i.e. social, environment and economic (as captured under the headline questions number 2, 3 and 4, representing a total of 15 value elements). While specific resource exchanges, or synergy projects, illustrate each of the value elements in these questions, the value contribution is less tangible and more indirect from the synergy development process with regard to the value elements in the other sustainability questions (i.e. around engagement, traditional activities, institutional arrangements and synthesis, respectively questions 1, 5, 6 and 7).

The differentiation between sustainability value from specific synergy projects and from the overall synergy development process is further expanded upon in Figure 4.1 (van Berkel 2006). The relative strength of the value elements is assessed on a qualitative 1 – 3 – 9 scale with 1 being '*generally beneficial*', 3 being '*specific contribution*' and 9 being '*highly beneficial impact*'. This is done with regard to both synergy projects, i.e. the specific physical resource exchanges, as well as the synergy process, i.e. as spin off from the efforts devoted to the development, evaluation and implementation of IS projects in the respective industrial area.



Note:
Ranking on a 1-3-9 scale, with 1 being '*generally beneficial*', 3 being '*specific contribution*' and 9 being '*highly beneficial impact*'. Full descriptions of the sustainability value elements are contained in Table 4.2

Figure 4.1: Relative contribution of synergy projects (specific physical exchanges of natural resources) and of the synergy development process to each of the sustainability value elements (source: van Berkel 2006)

The figure shows that the sustainability value creation is most profound at the project level. It is largely based on economic outcomes, including potential reduction of the costs of process inputs; potential increase of operating revenue through by-product

[3] Kwinana was chosen as the example to illustrate the value contributions given the far greater level of detail and familiarity with this example than any of the other case study regions.

sales; potential improvement in process efficiency and flexibility; and security of access to a vital resource for the business. It also covers environmental outcomes in regard to increase of overall resource efficiency, reduction of process emissions. At the process level, potential outcomes appear to be most significant in regard to governance (potential improvements in the regulatory framework), synthesis and continuous learning (through best practice sharing between businesses in the region).

Taken together, the limited quantitative benefit information (as summarised in Table 4.2) and the qualitative analysis of sustainability value elements (as summarised in Table 4.1 & 4.3 and Figure 4.1) justify a conclusion that IS projects are '*valuable*'. This applies most profoundly to economic and environmental benefits, while spin off social benefits and improvements in regards to governance and stakeholder engagement are also very plausible.

5. Enhancing Industrial Symbiosis Development

The findings reported in the preceding sections have provided a solid foundation for the next stage of the research to build on. The lessons on the enabling mechanisms are being combined and expanded to provide support for synergy developments for both companies and regional facilitators. For the company the support tool helps decisions and provides guidance on:

1. *Successfully engaging in an IS network* – guidance is intended to aid the companies in appreciating the benefits of IS networks. Networks have a number of benefits compared to individual efforts in finding potential synergies. The main advantage of a network is an increase in information flow between potential input-output partners, which increases the chances of finding a partner. The two most common methods of finding synergies are analysis of company inputs and outputs, and workshops. Virtually all synergy projects studied report that the majority of successful synergies emerge from workshops involving companies and not from software matching. Data collection can however help initially in isolating potential partners before a workshop to discuss potential synergies. Openness between companies (on information of outputs and inputs) is also highlighted as a strong contributing factor for successful synergy identification. Where there are severe confidentiality concerns, the data collection, its subsequent analysis and synergy identification can be performed confidentially by the network facilitating team (but again openness is often the key to success).
2. *Identifying potential synergy inputs and outputs* – a similar philosophy to eco-efficiency projects is taken (see for instance Bossilkov et al, 2005): e.g. involving all members of staff, brainstorming, suggestion boxes and incentive programs, tracking and communicating progress with staff.
3. *Assessing the benefits and motivational reasons for IS projects* – comprehending the full benefits of synergy projects. The evaluation tool, which is still being developed, will provide the basis for assessing the sustainability contribution. The key value elements of synergy projects (Table 4.3 and Figure 4.1) and the TBL considerations (Table 4.1) can help to identify the wider benefits of specific projects as well as the industrial symbiosis network. Guidance is being developed on identifying the full cost savings (e.g. the full costs of waste creation and its subsequent handling is often not identified in company accounting methods) and

other benefits such as innovation, technology development and knowledge/technology transfer within a network.

4. *Finding and creating markets* – although a IS network essentially provides the optimum platform to identify a synergy partner, in some cases there are ways that companies can begin to take on a more entrepreneurial role. This is especially true for companies that produce large by-product volumes (e.g. Scottish Power producing large volumes of fly-ash formed a joint venture with LaFarge to form a company that markets the use of ash (Harris, 2004)).
5. *Operational and contractual arrangements* – the five key determinants (ownership (of project assets); ownership and liabilities (traded resource); supply risks (availability of a critical process input); demand risks (utilisation of the recovered by-product or utility generated) and price (value of the exchanged resource for each of the synergy partners) (van Berkel, 2006)) provide the basis of guidance on identifying ways to share risks and benefits of synergy projects. This guidance then provides the platform for negotiation of successful synergy outcomes. It is useful in negotiation to split the process of utilising a by-product into three components (to decide which company will be involved in which component) where differing technologies and assets can be involved (Harris et al, 2006): *capture* (material/heat/water is taken from the 'source' production), *recovery* (technology used when the resource stream is recovered, separated into valuable components, transformed or mixed with another resource to form a usable by-product. Also refers to the transport or transfer) and *utilisation* (technology involved when the by-product stream is used in a 'sink' production process).

For regional facilitators the guidance being developed is based on a six stage process:

1. *Foundations* – assessing previous activities relevant to industrial symbiosis, building on local and regional strengths and sustainability projects. Identifying key industry and other stakeholders. Identifying common industry issues and problems for industry to collaborate on – i.e. beginning with simple projects that can help to build trust.
2. *Ownership and leadership* – forming a project steering group by giving ownership to key industry and other stakeholders (e.g. environment agency and local councils). Obtaining funding by linking in with regional and national strategies (the most prominent example being that of the National Industrial Symbiosis Programme that recently secured £13 million from government programmes (DEFRA, 2005)).
3. *Synergy development process* – identifying target companies and stakeholders to invite to a launch workshop with case study examples. Assessing the best network strategy for the region, types of workshops and software use etc. Creating task forces to aid technology dissemination or for single project research and development (e.g. major and combined research on inorganic residues).
4. *Feasibility and screening* – methods to screen out potential synergies into categories, for example from easy, short term wins, to those that require extensive research. Utilisation of the evaluation tool to assess the benefits of potential synergies.
5. *Implementation* – assist where possible in the implementation of commercially viable synergies.

6. *Monitoring, maintaining momentum and organisational learning* – keeping up the regular workshops and facilitating company interaction. There is also potential to extend the industrial symbiosis network to become a central part of a regional sustainability strategy (thereby continuing the focus on symbiosis and network momentum), and/or link the network with regional development. Networks and organisations are learning entities, and this should be acknowledged by the network facilitators who can potentially aid this process by offering training and influencing company strategy.

The emerging model will be evaluated and refined by applying it on potential and stalled (or failed) synergy developments. The model will also be evaluated in 2-4 regional industrial symbiosis projects in conjunction with other research projects being conducted at the Centre of Excellence in Cleaner Production (Bossilkov et al, 2005).

6. Final Comments

The review of industrial symbiosis developments has covered 22 examples worldwide and found that 162 distinct synergy projects had been implemented. Collectively, these provide testimony that regional synergies can deliver both competitive advantage and environmental benefit. The analysis was affected by the severe data limitations in some case studies but overall some important trends and lessons emerged. Eighty five per cent of the regions reviewed succeeded in implementing resource synergy projects suggesting that industrial symbiosis is '*achievable'*, i.e. that practical outcomes have been realized (van Berkel 2006).

Quantitative information on the benefits of industrial symbiosis was extremely patchy and at times difficult to interpret, but taken as a whole shows that industrial symbiosis can make a substantial contribution to sustainable development. In addition to the quantitative analysis the TBL life cycle approach and the 20 key value attributes of industrial symbiosis were proposed. Together they show that benefits transpire from both single IS projects (primarily related to cost and sales, flexibility of process and security of supply) and IS networks (primarily improvements in regulatory framework, and best practice communication between companies). Taken together, the three supporting analysis's support the conclusion that IS projects are '*valuable'* (van Berkel 2006).

Successful facilitation of industrial symbiosis appears to be based on five key ingredients: industry leadership; process management; synergy development activities (synergy workshops, input-output analysis, and third party identification); funding and promotion. These provide the basis for ongoing work to develop a model to support regional IS initiatives, whilst the evaluation model and the five key determinants for operational and contractual arrangements, provide the basis for developing support and guidance for development of IS projects.

The final stage of the research project will build on these mechanisms to propose the appropriate policy conditions and instruments to support and aid further IS developments.

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