Industrial Symbiosis in the Kwinana Industrial Area (Western Australia)

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Summary

The Kwinana Industrial Area of Western Australia has emerged as a world leading example of industrial symbiosis. This involves businesses in close proximity exchanging by-product material, water and energy. Utilisation of a previously discarded resource as an alternative input to another company can help improve both business and sustainability performance of the participating companies. For example, the exchange can reduce disposal costs and provide a cheaper input for the receiving company. The environmental benefits can include reduced collective resource consumption and waste generation, whilst the social benefits may include new employment opportunities and reduction of emission (e.g. water or traffic) to the local community.

This article presents the integrated research programme undertaken at the Centre of Excellence in Cleaner Production, Curtin University of Technology which seeks to enhance the uptake of industrial symbiosis in Australian heavy industrial areas. The case of Kwinana is discussed with illustrative case studies of industrial symbiosis exchanges. International interest in the creation of industrial symbiosis continues to grow and the article concludes with a discussion on the emerging role of measurement and control technology.

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 in close proximity. 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. 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).

In 2001 an economic impact study of the Kwinana Industrial Area (Western Australia) revealed the existence of significant numbers of industry interactions and also identified many more potential future IS exchanges (SKM 2002). Despite the benefits and desire to develop further IS exchanges many had not materialised due reasons such as: the perceived technical and contractual complexity; weak business case under current economic, market and regulatory conditions; or conflicting pressures on management and engineering resources within companies. In close consultation with the Kwinana Industries Council (KIC - the local industry group), its members and other industry bodies, Curtin University of Technology designed an integrated research strategy to support the realisation of further IS exchanges in Kwinana as well as in other heavy industrial areas. This research comprises of the following elements (see also figure 1):

- *Regional Case Study Developments* (represented in the centre of the diagram): practical support is provided for the identification and evaluation of new IS exchanges in heavy industrial areas and is funded by the Centre for Sustainable Resource Processing (CSRP). Current case study areas are Kwinana, Gladstone (Queensland, Australia), Rustenburg (South Africa) and Geelong (Victoria, Australia). Each case study includes collection and assessment of material, energy, water and other resource inputs and outputs by company, generation and screening of IS exchanges, and development of the business case for implementation of techno-economically feasible IS exchanges.

- *Research on Engineering Tools and Technologies*: This research project is also supported by CSRP and consists of two components. The first component has developed methods and tools for the identification and evaluation of potential IS exchanges. The second component involves the assessment of technological options for IS projects and a tool to help companies select and evaluate technological needs for potential IS exchanges.

- *Research on Enabling Mechanisms*: This research is supported by the Australian Research Council and the Kwinana Industries Council. It addresses the organisational challenges involved in the greater utilisation of industrial symbiosis. The research has assessed best practices from 22 regional industrial symbiosis developments and utilised the findings to develop and pilot test: (1) facilitating structures that encourage collaboration among industries operating in an industrial region; (2) a negotiation platform designed to help companies share the risks and benefits of IS projects and reach operational arrangements; and (3) evaluation tools that quantify the environmental, social and economic benefits of industrial ecology opportunities.

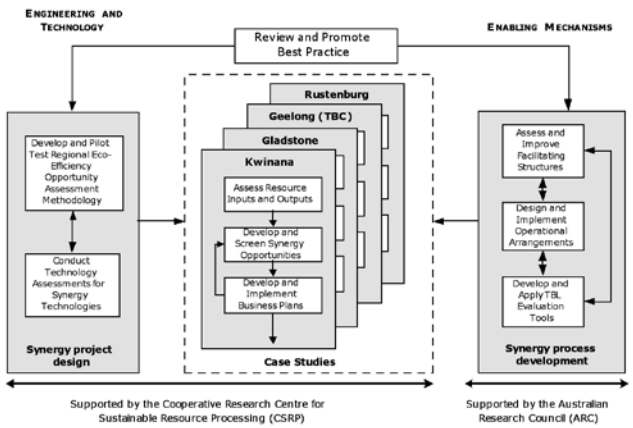

Figure 1: Structure and linkages of research into the application of industrial symbiosis in heavy industrial areas

Below we introduce the Kwinana Industrial Area where the majority of Curtin University of Technology research is focussed. Several examples of the industrial symbiosis in the region are discussed, highlighting the significant savings that can result. The ongoing research on fostering and supporting potential IS exchanges is then briefly discussed. Next a framework is introduced to consider the role of technology, measurement and control in facilitating IS.

Kwinana Industrial Area

The Kwinana Industrial Area (KIA) was established in the 1950s and is Western Australia's most significant heavy industrial region. The area of 120 km^2 is located approximately 40 kilometres south of Perth. About 3,600 people work in the area's core industries, and many more in related sectors and service jobs. The total economic output of the area exceeds A$4.3 billion annually (SKM 2002). The KIA is home to a diverse range of industries ranging from fabrication and construction facilities through to high technology chemical and biotechnology plants and large resource processing industries, such as titanium dioxide pigment production and alumina, nickel and oil refineries (see Figure 2). The instance of industrial symbiosis has considerably increased since the late 1980s, providing economic, environmental and social benefits to the companies involved, the neighbouring communities and the State.

Following the successful development and start up of two co-generation plants in 1997 and 1999, the KIC decided to explore further opportunities for IS exchanges in the area. A regional economic impact study was conducted and included an analysis of the principal material and energy flows within the area and the level of industrial integration (SKM 2002). This study revealed that between 1990 and 2000, the number of existing interactions increased from 27 to 106 (including 68 between core process industries and 38 with service and infrastructure industries). Each interaction represents either transfer of product(s), by-products or commercial cooperation. A review of material and energy flows in the area identified another 55 possible interactions but their economic and technical feasibility was not assessed at that time (Altham and van Berkel 2004).

Current IS Exchanges

The case study research based at Curtin University of Technology updated the inventory on existing industrial symbiosis in Kwinana and showed that the total number of industrial symbiosis exchanges

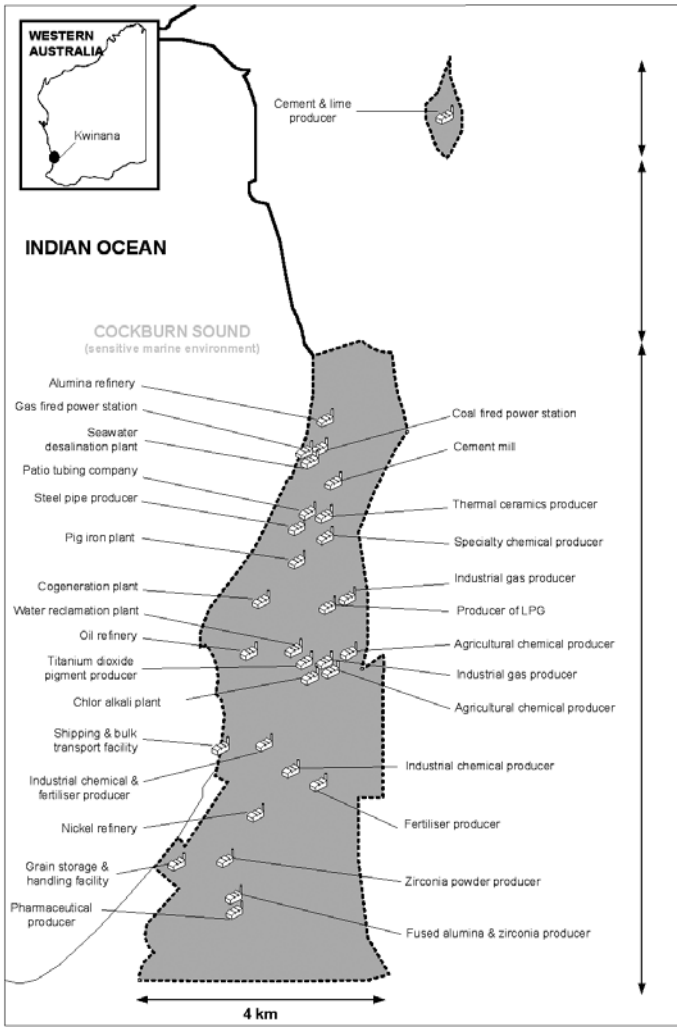

Figure 2: Location of companies in the Kwinana Industrial Area (van Beers, Corder et al. 2007)

already in place in Kwinana is 47, with 32 being by-product IS (figure 3) and 15 utility IS (figure 4).

Illustrative examples of the 32 current by-product IS include:

- *Chemical plant supplying gypsum for residue area amelioration at alumina refinery:* During the 1980's CSBP produced by-product gypsum (calcium sulphate) from the manufacture of phosphoric acid, which was stockpiled at CSBP's Kwinana site. This practice has ended but there remains a stockpile of 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. The material is now utilised by Alcoa alumina refinery (10,000 tonnes each year) to assist in plant growth and soil stability in its residue areas.

- *Chemical plant supplying carbon dioxide to alumina refinery residue area:* CSBP a major chemical and fertiliser manufacturer and Alcoa (alumina refinery) will soon supply Alcoa alumina refinery with by-product CO_2 to neutralise the alkalinity in its bauxite residue. The residue carbonation process aids the drying, management and stability of the residue area whilst producing a more benign residue with increased reuse opportunities (Alcoa, 2005). The CO_2 will arrive via pipeline from the nearby CSBP ammonia plant, resulting in GHG benefit equal to at least 70,000 tons CO_2 per year. The exchange builds on the relationship that developed from the gypsum exchange.

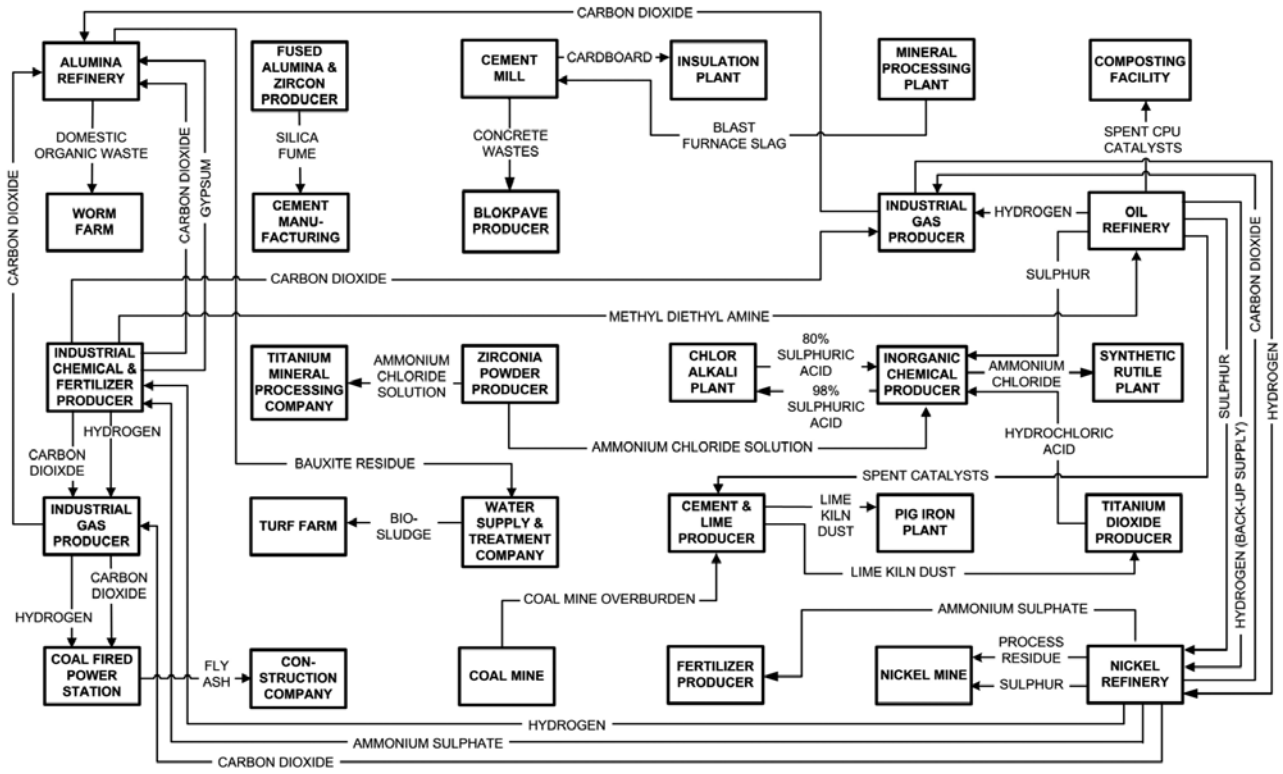

Figure 3: Existing by-product IS in the Kwinana Industrial Area. (van Beers, Corder et al. 2007)

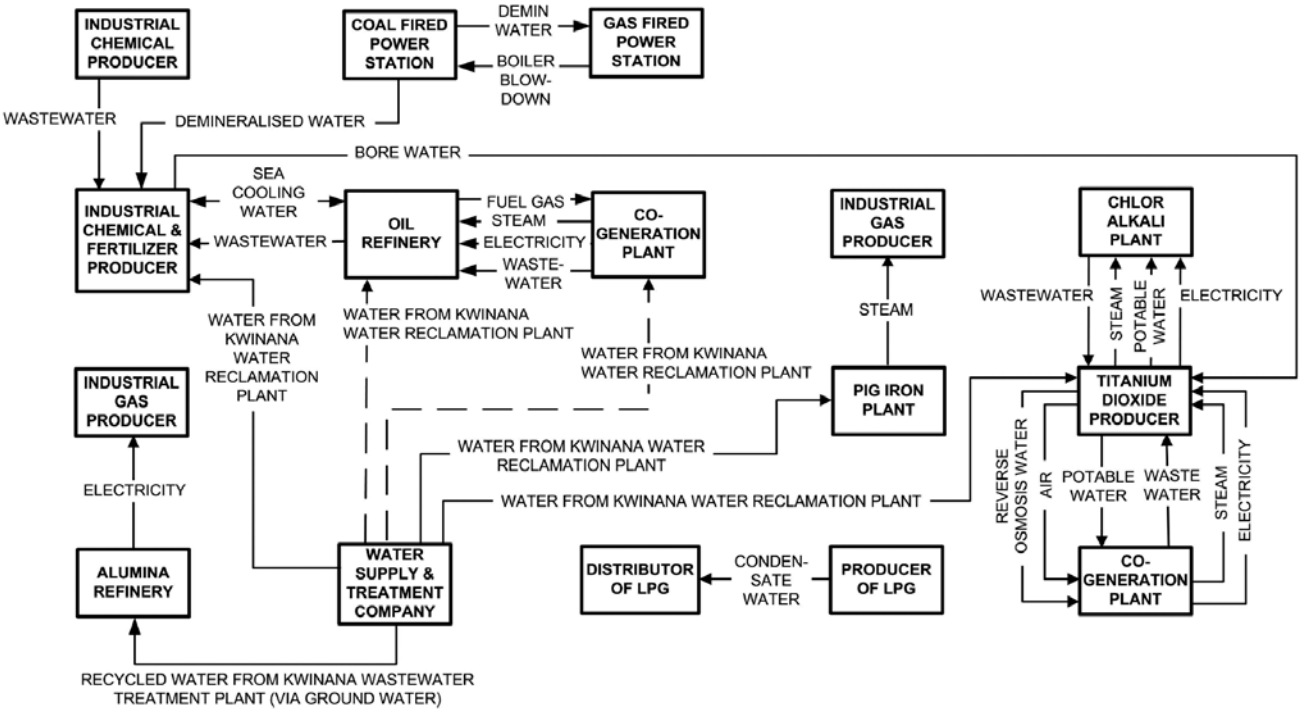

Figure 4: Existing utility IS in the Kwinana Industrial Area. (van Beers, Corder et al. 2007)

- *Emerging IS at the HiSmelt Pig Iron Plant:* The HiSmelt plant is the first commercial scale application of the direct smelting technology, which allows for simpler, more flexible iron making. It avoids coke ovens and sinter plants required for the standard Blast Furnace with a resultant reduction of emissions of 20% CO_2, 40% NOx and 90% SOx. Upon completion of commissioning (which began in November 2004) and successful commercial operation, the plant will source a number of by-products locally in the Kwinana area, such as lime, lime kiln dust and treated wastewater. In addition, the HiSmelt Process will utilise the WA reserves of iron ore fines, which are not currently suitable for blast furnace feed due to their high phosphorous content. The plant will produce a range of by-products such as slag and gypsum, with strong potential for IS exchanges.

- *Oil refinery providing hydrogen for city bus trial:* Hydrogen produced by BP as a by-product from its Kwinana oil refinery is piped to the BOC Gases (an industrial gas producer and supplier) facility where it is purified and pressurised. The compressed hydrogen is then trucked to the bus depot and off-loaded to the refuelling facility, from which the hydrogen fuel cell buses are refuelled. Perth is the only city in the southern hemisphere to be involved in this trial with three hydrogen fuel cell buses.

Illustrative examples of the 15 current utility IS include:

- *Combined heat and power plants*: There have been two recent installations of combined heat and power (CHP) plants at Kwinana. The Kwinana 116 MWh CHP plant was built in 1997 on BP Kwinana oil refinery's property. It meets all of the steam requirements for the refinery, and generates electricity for BP as well as the grid from excess refinery gas, supplemented with natural gas. This provides CO_2 savings in the region of 170,000 tonnes per annum in comparison to steam supplied from BP's boilers and electricity supply from the grid. The partnership with the Kwinana CHP also saved BP $15,000,000 in capital expenditure whilst ensuring a reliable, cost competitive source of steam and electricity. In addition, the refinery has achieved greater process efficiencies as a result of increased availability of high pressure steam and the CHP discharges its wastewater to BP's wastewater treatment facility. The second CHP was built in 1999 with a capacity of 40 MWh and is owned by the State's energy company Verve Energy. It provides power and superheated steam for the Tiwest pigment process needs, with the remainder of the electricity feeding the grid.

- *Kwinana Water Reclamation Plant:* The Kwinana Water Reclamation Plant (KWRP) is a joint initiative of the Water Corporation and the Kwinana industries and achieves the double benefit of greater overall water efficiency and reduced process water discharges into the Cockburn Sound (the adjacent sensitive marine environment). A micro filtration/reverse osmosis unit was built at a cost of A$ 25 million to produce a low TDS (Total Dissolved Solids) water supply from secondary treated effluent from the nearby Woodman Point wastewater treatment facility. This high quality process water is used by CSBP, Tiwest, Kwinana Cogeneration Plant, BP and HIsmelt to replace scheme water (6 GL/year, about 2-3% of the total scheme water use in the drought-affected Perth metropolitan area). The low TDS enables the process plants to cut chemicals use in cooling towers and other process applications, thereby reducing metal loads in their effluents. In exchange for taking water from the KWRP, the industries will be able to discharge their treated effluents into the deep ocean outfall through the Water Corporation pipeline, thereby eliminating process water discharges from the sensitive Cockburn Sound.

Potential Industrial Symbiosis

The overall objective of the case study research (represented by the middle box of Figure 1) is to provide hands-on support to the companies in Kwinana to develop, evaluate and implement IS opportunities. Potential IS exchanges were identified through four activities: the Kwinana Input/Output Database; review of earlier reports on IS opportunities in Kwinana (in particular the 2001 economic impact study (SKM 2002); discussions with company representatives; and focused opportunity identification workshops. By June 2006, the project had identified more than 90 potential IS projects. These were subsequently screened using a developed "Synergy Screening Tool" that rated IS exchanges in terms of ease of implementation, business case and sustainability benefits.

The main focus of the Kwinana Synergies Project is currently (van Beers 2006):

- Industry assistance to selected IS opportunities : recovery and reuse of sodium sulphate; reuse of liquid ammonium sulphate; reuse of graphite electrodes; recovery and reuse of catalysts; recovery and reuse of organic waste; use of demineralised water, reuse of treated effluents for dust suppression and wash-down water; and treatment of oily wastewater

- Foundation research on a collective KIA strategy for inorganic by-products reuse : This by-product comes from past operations (e.g. gypsum) and current operations (e.g. bauxite residue, kiln dusts, fly ash, iron making slag).

- Foundation research on a collective KIA strategy for water reuse: A baseline assessment of water inputs and outputs for the ten major water consuming companies (which together use over 30 GL water/year) has been conducted. This included brainstorming sessions with company staff on opportunities for exchanges of water between industrial operations, joint water treatment, and joint storage of water.

- Foundation research on collective KIA strategy for energy recovery: This component is assisting the major energy consuming industries in KIA with the identification of utilising low-grade heat, a significant energy loss in many Kwinana processing operations.

The role of technology

The experience gained from the integrated research program and the preliminary stages of the enabling mechanisms research (represented by the right hand side of Figure 1), which examined industrial symbiosis developments in 22 global case study regions, suggested that three success factors are necessary for the successful realisation of industrial symbiosis opportunities (van Berkel, 2006):

- *Convincing business case*: the IS exchange reduces costs, generates new revenue and/or secures access to vital resources, in a manner that can be realised by one or more businesses.

- *Societal licence to operate*: at the minimum all government approvals should be in place, but preferably also endorsement from affected communities, key Non-Governmental Organisations and/or opportunity to create or improve skills, jobs and livelihoods; and

- *Proven technology*: process and equipment are available to make the IS exchange happen, so that the resource is being transferred between the companies involved and converted as and when required.

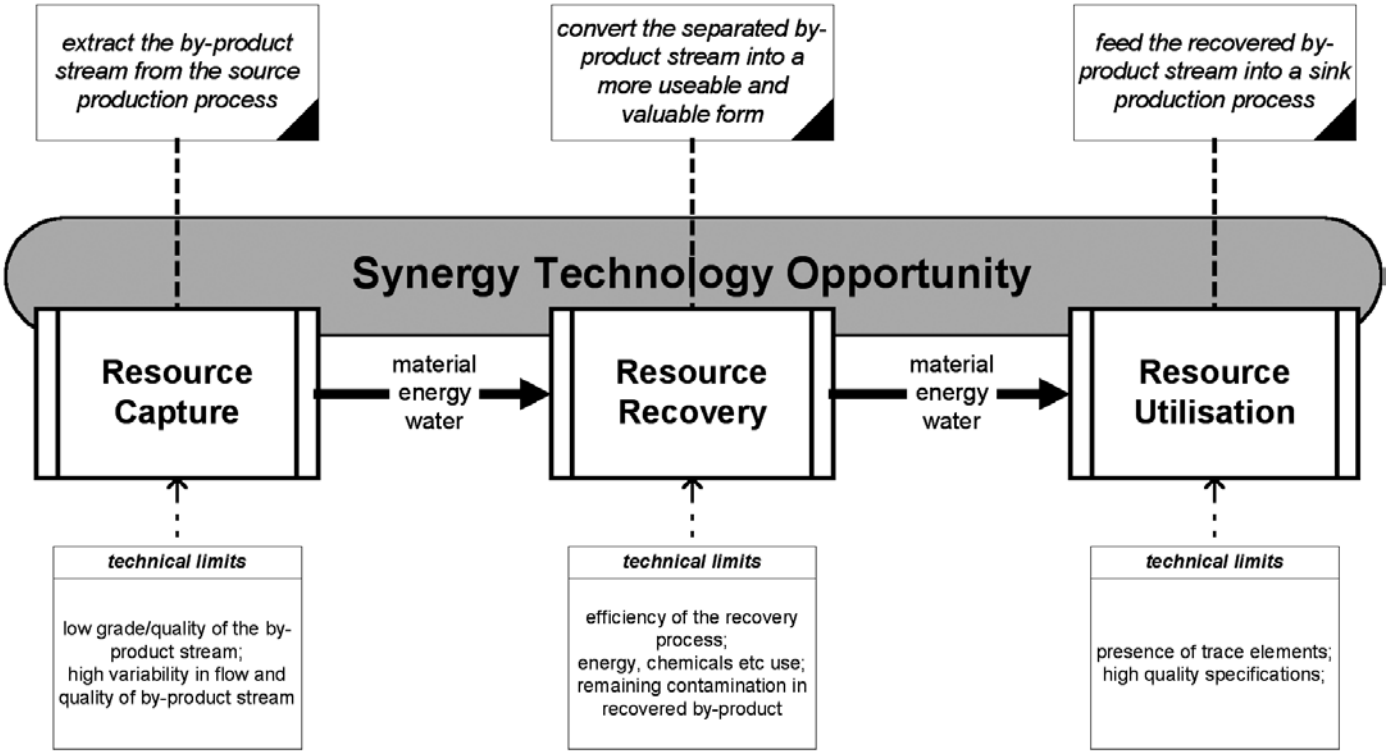

Figure 5: Technology components for realisation of IS opportunity (based on Harris, Corder et al, 2006)

The findings suggest that failure to meet any of one these makes it extremely unlikely that the respective IS exchange can succeed. However, meeting all three will not automatically result in the implementation of the exchange (van Berkel, 2006). From these success factors the important role that technology plays in enabling IS becomes apparent. In addition, in many of the regions studied evidence suggests that the most easily achievable IS exchanges have been achieved. It appears that the realisation of further IS will require the either the development of suitable technology or a package of suitable technology (sometimes the availability of suitable technology may not be known by the companies).

In order to assess the role of technology in the realisation of IS exchanges, an analytical framework was proposed that breaks down an IS exchange into three components (as in Figure 5) (Harris, Corder et al. 2006):

- *Capture* refers to how the material/heat/water is taken from the 'source' production process. This also recognises that the composition, or quality of a by-product stream, is dependent on the technology and processes used in production.

- *Recovery* refers to the technology used when the resource stream (water/heat/material) is recovered, separated into valuable components, transformed or mixed with another resource to form a usable by-product. The transport and storage (enabling infrastructure) of by-products is also important and is considered under the recovery/management component.

- *Utilisation* refers to the technology involved when the by-product stream is used in a 'sink' production process.

To illustrate the framework, consider Tiwest in Kwinana, WA, which in the manufacture of titanium dioxide pigment generated a dilute hydrochloric acid from the scrubbing of the tail gas from the chlorinators, which was being neutralised in the company's wastewater treatment plant. Tiwest installed a second scrubber to be able to *capture* most of the hydrochloric acid as a weak acid that could be taken by the nearby Coogee Chemicals works, to produce ammonium chloride (the *recovery* stage) that can be used by the Tiwest rutile plant (the *utilisation* which requires minor adjustment to feed by-product ammonium chloride).

For each of the by-product groups of water, energy and material different challenges exist in enabling new IS exchanges.

For IS exchanges involving water, the economic treatment for reuse remains a challenge when compared to standard water sources. There are many mature water treatment and recovery technologies, and the principal challenge appears to be to package treatment and recovery technologies in a customised recovery scheme. Some of the technologies particularly relevant for IS such as reverse osmosis continue to improve and become cheaper. With rising water prices likely in many regions (particularly in Australia, but also in other parts of the world) it may only be a matter of time before reuse becomes the preferred option (or even the necessity). A challenge of technology for IS involving water remains the continuous online monitoring (or real time) of quality and potentially harmful contaminants. The majority of current methods for on-line monitoring give indirect indicators (e.g., conductivity, membrane pressure) and further research is needed to relate newer methods (e.g., UV/VIS spectroscopy, electrochemical sensors) to specific quality measures. Also inorganic fouling remains problematic with many compounds only being identified after a problem has occurred. Research is needed to better predict precipitants and develop suitable control measures.

In terms of IS involving energy, heat recovery technology is well established in particular for generating power from high-grade waste heat derived from processes. Recent examples demonstrate that even recovery of lower grade waste heat can be profitable, either as a lower grade process heat input (for example at Alcoa's Pinjarra Refinery, (van Berkel and Narayanaswamy 2005)) or even to drive major pieces of equipment (for example at the HIsmelt pig iron plant the

use of medium pressure steam to drive air compressors (van Beers, 2006)). An extension of such schemes over company boundaries is in principle possible, even though the techno-economic viability decreases quickly with increasing distances. This could however in principle be overcome with emerging integrated heat transfer and storage concepts utilising for example phase change materials.

Material by-product IS covers the re-use of a wide range of solid, liquid and gaseous by-products. While recovery processes are conceivable for many materials, their application typically depends on measurement and control, and preferably reduction or elimination of minor elements from the by-product stream. Gaseous streams may require selective and efficient concentration of certain materials whilst better process controls in hot processes can be required to manage hazardous emissions that can occur from the use of alternative fuels and raw materials. There may also be a future role in monitoring and controlling low-level contaminants that may have high risk (such as heavy metals in alumina refinery residue).

Conclusion

This article has introduced the research work on industrial symbiosis being undertaken at Curtin University of Technology in Western Australia. The work largely focuses on the Kwinana Industrial Area which in recent years has emerged as leading example of industrial symbiosis. During the years between 1990 and 2000, the number of existing interactions increased from 27 to 106, and the total number of industrial symbiosis projects grew to 47. The extensive network of exchanges was shown and specific examples highlighted that IS can result in significant sustainability (i.e. social, economic and environmental) and business benefits.

The significant role of technology, measurement and control in enabling IS exchanges was discussed. This is set to grow as research and interest in IS increases due to the rising awareness that IS offers an excellent way for industry (and regions as a whole) to simultaneously improve its economic, environmental and social performance. With recent (yet to be made public) events at Kwinana there are signs that companies are now seriously considering industrial symbiosis in the design stage of future operations, which is a major step forward on the road to sustainability.

Acknowledgements

This article utilises and builds on work from several researchers, past and present, of the Centre of Excellence of Cleaner Production. The author would therefore like to acknowledge the contribution to this article of: Dick van Beers, Albena Bossilkov, Rene van Berkel and Jim Altham.

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The role of audited benefits in Industrial Symbiosis: The U.K. National Industrial Symbiosis Programme

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D. Rachel Lombardi, Research Fellow, University of Birmingham, UK

Executive Summary:

The UK National Industrial Symbiosis Programme (NISP), the first national industrial symbiosis (IS) programme, is 'sustainability in action', accruing environmental, economic and social benefits. NISP brings together companies and organisations of all sectors and sizes, generating significant environmental benefits such as reduced greenhouse gases and landfill diversion, as well as cost reductions and new sales. This in turn encourages economic activity, which generates further social benefits with the creation of new businesses and jobs, and stimulates process improvements for industry through innovation and new technologies. For the NISP practitioner, quantification of IS benefits is vital to substantiate the business case necessary to secure engagement with industry, and to secure credibility and hence funding from government, underscoring the importance of metrics and measurement in industrial symbiosis programmes. The external audit system was put in place to demonstrate value for money from a novel business-opportunity approach to accomplishing the goals, both economic and environmental, of the programme's funders. However the benefits of measurement have gone well beyond this initial need to helping the programme directors understand the needs of the participating companies, and areas for improvement in the programme's operations.

Introduction to NISP

The National Industrial Symbiosis Programme (NISP) is the only fully externally audited programme of the Department for Environment, Food and Rural Affairs' (DEFRA) Business Resources and Waste (BREW) funded programmes in the UK. Managed by International Synergies Ltd, NISP is one of a number of initiatives helping industry