Emulating nature

The rise of industrial ecology

Industry is looking to nature's examples of sublime efficiency to find ways to improve the sustainability of our production and consumption systems.

At the Kalundborg industrial park in Denmark, one industry's unwanted by-product has become another's sought-after process input. Central to this heavy industrial complex are a coal-fired power station and oil refinery, which exchange waste steam, waste heat, waste water and waste gas amongst themselves and neighbouring industries, saving thousands of tonnes in greenhouse gas emissions per year and reducing water consumption by 25 per cent.

Fly-ash, clinker and sulphur by-products are used by neighbouring industries to produce useful products, such as cement, thereby reducing landfill. Waste heat from the power station and refinery is also piped to nearby fish farms and residential houses – replacing some 3500 household oil heaters.[1]

Kalundborg is an increasingly recognised example of 'industrial symbiosis'; part of the broader, emerging 'industrial ecology' concept, which uses nature as a model for optimal material and energy flows, and to inspire environmentally oriented product and process designs.

'The concept of industrial ecology is still evolving and different people will view it in different ways,' says Professor Rene van Berkel, leader of the Regional Synergies Research Program at the Centre for Sustainable Resource Processing (CSRP) in Western Australia.[2] 'But the end result is economic, environmental and, in some cases, social sustainability.'

A key part of industrial ecology, and industrial symbiosis in particular, involves improving resource efficiency – getting the maximum value out of our resources without harming the environment. This means changing the linear nature of industrial systems – where raw materials are used, products are made and by-products are then disposed of – to a cyclical or 'closed loop' system, where the by-products are reused as energy or raw materials for another product or process. This closed loop system is based on natural ecosystems, where nothing is wasted – the by-products from one organism or process form the food source or raw material for another.

For example, at Kalundborg and other eco-industrial parks globally, material, energy and water exchanges between companies conserve natural and financial resources, and reduce production, material, energy, insurance and treatment costs and liabilities. They also enhance operating efficiencies and quality control, reduce exposure risks for the local population, and realise potential income through the sale of by-products and waste materials.

The success of Kalundborg's industrial symbioses is the result of gradual evolution rather than grand design. Like all industrial symbioses before and since, they are characterised by the close geographic proximity of the industries, open communication, a diversity of enterprises, and large, continuous by-product streams from two or more major process industries, which can be utilised by neighbouring industries.

Facets of industrial ecology

The thrust of Kalundborg and the concept of industrial ecology into international consciousness is largely credited to an article that appeared in *Scientific American*

1 www.symbiosis.dk
2 The Centre for Sustainable Resource Processing (www.csrp.com.au) aims to find technological solutions to eliminate waste and emissions, and to reduce energy and water consumption, in mineral processing.

Fly-ash, clinker and sulphur by-products are used by neighbouring industries to produce useful products, such as cement, thereby reducing landfill.

WA's expanding Kwinana Industrial Area is already an international best practice example.
Courtesy Kwinana Industries Council

in 1989.[3] Written by General Motors Vice-President Robert Frosch and his colleague Nicholas Gallopoulos, 'Strategies for manufacturing' promoted examples of industrial activity that 'functioned as analogues of biological ecosystems', to achieve greater sustainability.

Industrial ecology has since become a rapidly evolving field of research, public policy and industrial practice.[4] The concept can be applied to sustainability issues in systems of production and consumption in two ways: through a 'systems' approach, or a 'product/process' approach.

The systems approach applies ecosystem principles to move from the linear resource flows (resource–product–waste) to circular flows, where waste is minimised and recycled. Systems applications include:

- Industrial metabolism – studying the physical processes that convert raw materials, energy and labour into finished products and wastes;
- Materials flow analysis – following the flow of resources from harvest or extraction to disposal or recycling[5]; and
- Industrial symbiosis – engaging traditionally separate industries in collaborative ventures involving the physical exchange of materials, energy, water and/or by-products.

The product/process approach, meanwhile, uses nature as an analogue, mimicking natural, biological, chemical, physical and geological processes and materials in industrial applications. The aim is to develop new processes and products that are more resource efficient and compatible with nature. Applications include:

- Biomimicry – using nature to inspire the development of cleaner products, materials and processes[6];
- Green chemistry – designing, developing and implementing chemical products or processes that reduce or eliminate the use and generation of hazardous and toxic substances[7]; and
- Green engineering – aiming to improve the economic and environmental performance of industrial processes by optimising process design and operating conditions[8].

In Australia, major research efforts have so far focussed on industrial symbiosis. At the Kwinana Industrial Area in Perth, and in Western Australia's wheatbelt, projects that embody the concept of industrial symbiosis are already contributing to sustainable development.

The Kwinana Industrial Area

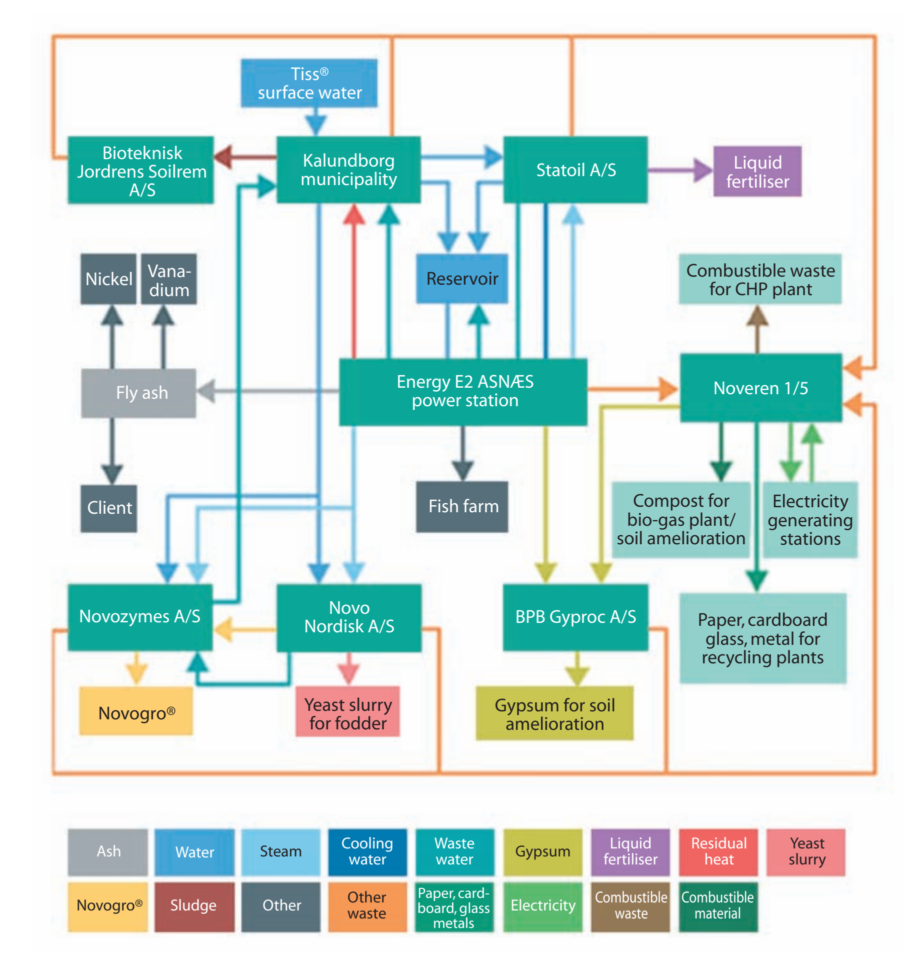
Thirty-five kilometres south of Perth is Western Australia's premier industrial zone, and a leading example of industrial symbiosis or 'regional synergies' globally. Established in the 1950s following a special Act of Parliament, the Kwinana Industrial Area (KIA) now boasts some 40 major process, utility and service industries. These include a range of refineries and chemical producers, power stations, cogeneration plants, port facilities, and water and waste-water treatment plants. The KIA employs more than 4000 people and contributes more than $4.3 billion annually to the national economy.

Like the Kalundborg industrial park, the industrial symbioses at Kwinana have evolved opportunistically, rather than by design. But unlike other symbiotic ventures, Kwinana has its own industry representative organisation. Established in 1991, the Kwinana Industries Council (KIC) is comprised of members from 14 major industries in the KIA and associate members from 25 other medium-sized industries and service providers.[9]

KIC Director, Ms Tonia Swetman, says the council addresses a range of issues common to Kwinana's major industries, and seeks to foster positive interactions between member companies and between industry and the broader community. This level of communication and interaction has led to an unprecedented number of industrial synergies, which were identified in an economic impact study of the KIA, commissioned by the council in 2001.[10]

'There are 47 industrial synergies in place now – 32 by-product synergies, involving the reuse of solids, liquids or gasses, and 15 involving the shared use of utility infrastructure,' Ms Swetman says.

3 Frosch RA and Gallopoulos NE (1989). Strategies for manufacturing. *Scientific American* **164**: 94–102.
4 Regional Synergies for Sustainable Resource Processing: A Status Report. http://www.csrp.com.au/_media/pdf/3A1StatusReportJune2005Final.pdf
5 An example of materials flow analysis can be found in the evaluation of the recovery potential of secondary metals (from mining and production) by the CSRP and Yale University.
6 Biomimicry projects are well established (although they may not be identified as such) and include CSIRO's work on artificial photosynthesis, and new research into biomimicry as an agent for sustainable practices on Western Australia's south coast.
7 In Australia, green chemistry has an increasing profile through the Centre for Green Chemistry at Monash University and the University of Western Australia.
8 The Natural Edge Project (www.tnep.net) teaches and implements green engineering principles.
9 Kwinana Industries Council: www.kic.org.au
10 Kwinana Industrial Area Economic Impact Study: an example of industry interaction. April 2002. www.kic.org.au/SiteContent/ReportsandMedia/reports.asp?y=2002



Heavily interlinked processes at Kalundborg industrial park in Denmark demonstrate the feasibility and mutually beneficial outcomes of industrial ecology. From www.symbiosis.dk

Here are some examples of the closed loop processes at the site: BOC Gases separates, cleans and pressurises hydrogen from the BP oil refinery for the hydrogen bus trial in Perth[11]; Air Liquide purifies and compresses carbon dioxide from other industries for use in soft drinks, beer, dry ice and water treatment; and the Kwinana Water Reclamation Plant takes secondary treated effluent from a nearby waste-water treatment facility to produce water that is used by four industries, replacing up to three per cent of scheme water taken from the Perth metropolitan area.

'The diversity and maturity of existing synergies in Kwinana is remarkable, both in absolute terms and in comparison to famous international examples such as Kalundborg,' Ms Swetman says. 'This strongly suggests that regional synergies in Kwinana are making a contribution to sustainable development at a regional scale.'

So what makes these synergies work? According to Ms Swetman it is the diverse blend of key processing and manufacturing industries, which primarily produce products for international markets, and which experience limited local competition. The gradual encroachment of residential development around the area and the recognition by industry of natural resource values in the nearby coastal environment have also triggered economically, environmentally and socially responsible initiatives within the KIA.

However, the establishment of industrial synergies is not easy, nor necessarily of immediate benefit to the industries concerned. The KIA economic impact study found other opportunities that have not yet been pursued because of their perceived technical or contractual complexities (confidentiality, liability, quality fluctuations); unfavourable economic, market and regulatory conditions; or difficulties redirecting management and engineering resources away from core business and into research and development.

'The challenges and barriers that need to be overcome to achieve industrial symbiosis are often underestimated,' says Professor van Berkel.

'Many synergies are not core business, so there's no driver to invest resources to pursue them. There may also be community opposition to the use of one company's output as an input by another. Legislation, too, can be a barrier – if by-products are classified as hazardous waste, they are stigmatised, and the costs for meeting regulatory provisions increase exponentially. And, sometimes, the technology just isn't available.'

So why pursue industrial synergies?

'Companies may take a more expensive, but environmentally favourable option, to reduce costs down the track,' Ms Swetman says. 'There are hidden benefits, such as improved relations with the community or regulators, which may make approval for future ventures easier. Some synergies may also mean the difference between a business being economically viable, or not, because of reduced transport costs or a guaranteed and cheaper supply of input material.'

Realising synergy opportunities

To help address the challenges, and to proactively pursue unrealised synergy opportunities, CSRP and KIC initiated the 'Kwinana Industries Synergies Project' in 2004.[12]

'The project will pursue synergy opportunities in four areas,' Ms Swetman says.

'It will look at value-adding inorganic process residues, such as fly-ash and gypsum; recycling non-process waste such as packaging and food scraps; reducing energy consumption and greenhouse gas emissions through improved technology and the capture and use of waste heat; and water conservation.'

The project is part of a comprehensive research program implemented by Curtin University of Technology and the University of Queensland, led by Professor van Berkel, with funding from the Centre for Sustainable Resource Processing, the Australian Research Council, and KIC and some of its member companies. The program involves:

11 Davidson S (2003). Perth's hydrogen bus trial. *Ecos* 116: 6.
12 Capturing Regional Synergies in the Kwinana Industrial Area: 2005 Status Report. www.csrp.com.au/_media/pdf/3B1StatusReportAugust2005Final.pdf

- Identifying and evaluating potential synergies in heavy industrial case study areas – currently Kwinana and Gladstone (Queensland).[13] Each case study involves collection of input and output data from companies, and the development of business cases for 'techno-economically' feasible synergies;
- Developing novel tools and technologies needed to establish regional synergy projects[14]; and
- Research into 'enabling mechanisms' – finding the right incentives and mechanisms for industries to start collaborating and to share the risks and benefits associated with synergy developments.

At Kwinana, the project has so far produced a database containing information on the inputs and outputs of 30 companies. From this, 87 potential synergy projects were identified, with six short-listed for feasibility assessment. The database will also allow new companies thinking of entering the KIA to assess the feasibility of establishing new synergies with existing members. The project will continue to enhance Kwinana's triple bottom line benefits, which are already well beyond the scope of what can be achieved by industries in isolation.

Clockwise from top left: The demonstration integrated wood processing plant running at Narrogin, WA. Mallee belts around a wheat crop in the Lake Toolibin catchment. Mallee belts do not require fencing for protection from sheep grazing. WA Conservation and Land Management

The Oil Mallee Project

Agricultural systems, too, are a logical target for the application of industrial ecology principles. According to Mr John Bartle of the Department of Conservation and Land Management (CALM) in Western Australia, Australia's agricultural systems have the potential to produce substantial supplies of renewable biomass, which could reduce our dependence on fossil fuels and underpin new industries. However, Australia has focussed its agriculture into food production, in an era of continuous regression of food commodity prices. These food crops are annual, winter-growing plants which generate large, unpaid economic and environmental costs from salinity.

'We could better manage our environment and our agricultural economics if we complemented our annual crops with perennial woody crops that could be processed locally into industrial products,' Mr Bartle says.

The Oil Mallee Project, involving CALM, the Oil Mallee Company[15], Enecon[16] and Western Power Corporation[17], is a developing example of industrial and agricultural symbiosis in the low rainfall, salinity affected regions of Western Australia's wheatbelt, which could address these concerns.[18, 19]

The project aims to remedy waterlogging and salinity through the planting of mallee trees and subsequent 'integrated processing' of the trees to produce activated carbon from the wood (using CSIRO technology), eucalyptus oil from the leaves, and electricity via combustion or gasification of the biomass.

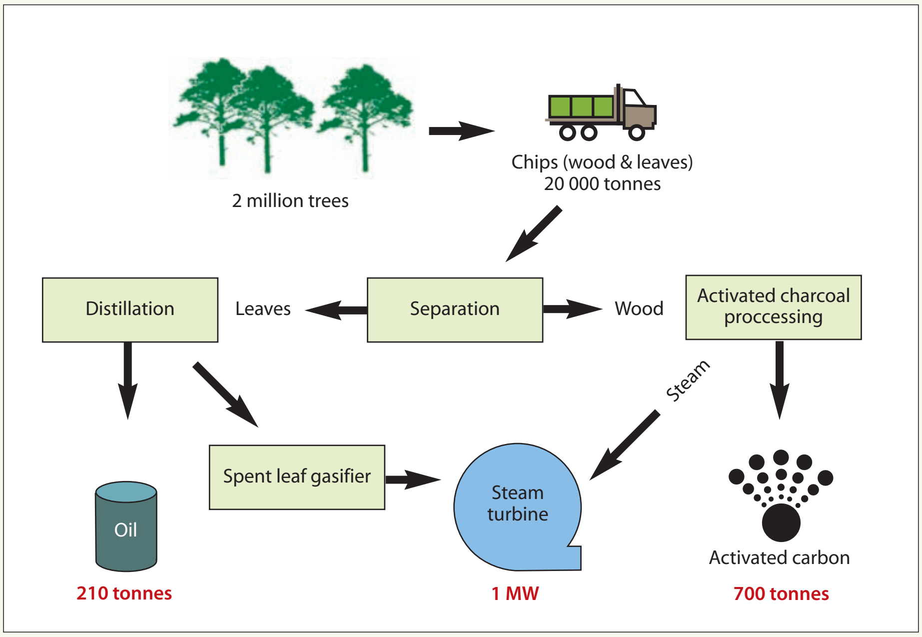
After years of research, CALM identified the mallee as an economically and environmentally viable candidate for salinity control in the region. As mallee can re-sprout from its large underground lignotuber (the mallee root) after removal of the above-ground parts (a process called 'coppicing'), it can be harvested every three to five years and remain in a state of rapid growth, producing biomass at a low financial and energy cost, and absorbing water and carbon dioxide. To enhance water use and productivity, mallee is planted in contour belts 5 to 10 m wide, with 100 m wide bays or 'alleys' of annual cropland between.

About 1000 wheatbelt farmers (20 per cent of all wheatbelt farmers) have planted at least some mallee since 1994, when CALM initiated the project. There are now 30 million mallees, or about 11 000 hectares, planted. Mr Bartle says farmers have been quick to realise the importance of planting in belts, and have devised

13 *Potential Synergy Opportunities in the Gladstone Region*. June 2005. www.csrm.uq.edu.au/docs/Synergies%20Report%20Jun05.pdf
14 Regional Synergies for Sustainable Resource Processing: A Status Report. www.csrp.com.au/_media/pdf/3A1StatusReportJune2005Final.pdf
15 www.oilmallee.com.au
16 www.enecon.com.au/tree.html
17 www.westernpower.com.au
18 Bartle J (2005). Practical and economic issues relating to short rotation coppice crops: international experiences and options for Australia. *Residues to Revenues Conference*, October 2005.
19 Bartle J and Shea S (2002). Development of mallee as a large-scale crop for the wheatbelt of WA. *Proceedings Australian Forest Growers 2002 National Conference*.

Progress

The low unit value of biomass also means that it is locked into local processing, thereby supporting regional development.



Production pathways for a 1 megawatt integrated wood processing plant. www.oilmallee.com.au

efficient methods for integrating mallee belts into their conventional systems.

'The confidence demonstrated by farmers, and the promise of mallee production systems, has encouraged Western Power Corporation to invest in mallee processing,' Mr Bartle says.

'In particular, the ability of the farmers to demonstrate that they could deliver a consolidated stream of biomass, thereby making a widely dispersed resource attractive to commercial utilisation, was a critical factor. Efficient grower organisation is essential for this type of woody crop, which can only achieve commercial yield when grown on less than 10 per cent of the farm, and which requires complex integration with agriculture.'

A $15 million integrated wood processing demonstration plant with a capacity for 20 000 tonnes of mallee a year is now nearing completion at Narrogin, 200 km south-east of Perth. Designed and constructed by Western Power and Enecon, the plant will use biomass from 4 million mallees from nearby farms. The leaf fraction will produce eucalyptus oil (which has potential for large scale use as an industrial solvent), the wood fraction will be converted to activated carbon (for use in water treatment, gold recovery and the food and beverage industry), and biomass residue (leaf, twig and bark) and waste heat will be used to generate electricity.

If the demonstration plant succeeds, full-scale plants processing more than 20 million trees could be built. Western Power believes there is potential for at least nine processing plants in Western Australia, with more possible in other states and overseas.

However, Mr Bartle says activated carbon markets are comparatively small and could not support new woody crops on a scale large enough to achieve extensive salinity benefits. This has stimulated interest in the full range of products and industries that might use woody biomass.

'The major areas are manufactured wood products like panels and paper, charcoal for metallurgical use, chemicals, bioenergy (both electricity and transport fuels) and manufactured stock feeds,' he says.

'The Centre for Sustainable Resource Processing, for example, is undertaking research into the production of charcoal from the leaf and twig fraction, and its subsequent use in novel pyrometallurgical (heat-based ore refining) reactors.

'To expand the product range, it makes sense to look at other woody crop species and we've got a huge diversity of well-adapted native plants that could be used in this way.'

A national research and development project called Florasearch (supported by the Salinity CRC[20] and the Joint Venture Agroforestry Program[21]) is already underway to select and develop native species for this purpose.

Mr Bartle says the development of mallee cropping may lead to more extensive application of the principles of industrial ecology in agriculture. Woody crops have great potential to produce a large biomass resource, which, through using smart design, may contribute to solving environmental problems and building a more sustainable agricultural system. The low unit value of biomass also means that it is locked into local processing, thereby supporting regional development. Mr Bartle says local processing industries could then use their residues to produce energy and desalinated water, which are expensive to deliver through large centralised systems.

In addition, biomass crops have a large capacity to carry sequestered carbon and, when harvested, to replace the use of fossil fuels. The coppicing ability of woody crops, like mallee, means that they have a large energy input/output ratio and will be increasingly competitive in a world with escalating energy costs. The coppicing could also mean potentially cheaper wood chips through more frequent but lower cost harvesting, compared to chips made by conventional forestry wood producers.

'These factors indicate that large, decentralised industrial biomass processing hubs could emerge in the wheatbelt,' Mr Bartle says.

'But such a vision will only be realised if we invest more heavily in research and development.'

● **Wendy Pyper**

More information:
Industrial Symbiosis of Kalundborg: www.symbiosis.dk
Kwinana Industries Council: www.kic.org.au
The Oil Mallee Project: www.oilmallee.com.au

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20 Also called the CRC for Plant-based Management of Dryland Salinity: www.crcsalinity.com.au
21 See Rural Industries Research and Development Corporation: www.rirdc.gov.au