Capacity Building and Resource Exchange Kwinana Industries – A Western Australian Contribution to Industrial Ecology

Examining Mechanisms for Sustainable Industrial Development

Keywords: Industrial Ecology, Kwinana, Sustainability

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Contents

List of Figures

Abstract

The sustainability of Western Australia's economy, society and environment is fundamentally affected by industrial metabolism and associated induced resource flows. Several indicators of Australia's resource economy suggest that massive dematerialisation, decarbonisation, and detoxification of industrial material flows will need to begin in the near future if the resource economy is to become sustainable in the longer term.

The paper examines industrial ecology in its potential to inform and deliver the necessary restructuring of Australia's industrial metabolism along a sustainable trajectory of development. In this sense, the Kwinana industrial area in Western Australia is recognised as an internationally significant example of industrial symbioses. Contributions to industrial efficiency have occurred through the evolutionary development of a complex resource exchange network involving at least 28 heavy industries in the Kwinana industrial strip. The Kwinana resource exchange network is compared with a well documented though smaller example of industrial symbioses involving 8 industries in Kalundborg, Denmark.

Industrial ecology in its manifestation as industrial synergy is critiqued in its capacity to provide a platform for sustainable industrial development. The establishment of resource exchange networks among industrial firms has contributed significantly to energy and resource efficiency at the industrial firm or estate level. While component efficiency may be a characteristic of a sustainable materials economy, alone it does not provide a comprehensive means to get there. Industrial synergy in this sense may in fact promote unsustainable path dependant development, and is an inadequate vehicle for the delivery of industrial sustainability outcomes at the broader level of industrial metabolism. Demand-side management supporting the shift to a service-oriented economy is briefly explored as a policy option addressing overall system efficiency while also driving the desirable efficiency of industrial metabolic components such as the industrial firm.

In advocating industrial symbioses, the ecological metaphor employed by industrial ecologists is largely informed by a reductionist and mechanistic understanding of natural systems. This paper explores a deeper, more holistic understanding of the organisational system dynamics of industrial economics and development institutions, informing a potentially more robust model for the sustainable development of industrial systems.

The region of Kwinana -Rockingham is referred to as a significant evolving example of institutional and organisational ecology among industrial development stakeholders. Cooperation, information transfer and capacity building between industry, community, and the public sector represents a more promising articulation of industrial ecology, and potentially provides a powerful vehicle for the delivery of industrial sustainability outcomes on a regional and regulatory level. By fostering community–industry partnerships, the industrial firm can optimise sustainable development outcomes through participating in a shared regional vision and strengthened sense of place. Therefore, a collaborative and ecological industrial development process allowing broad participation and emphasising the development of human capital is suggested as a significant and pragmatic contribution to the broader industrial sustainability agenda.

Background Narrative

Industrial development is the fundamental overarching factor that has, and continues to afford increasingly higher standards of sustenance to rapidly growing human populations in an increasingly degraded and depleted global environment. Technological improvement, scientific insight, and urbanisation afforded by widespread industrialisation of the developed world have lead to a remarkable revolution of the human condition.

Life expectancy has increased worldwide to more than double that of preindustrial human history, with a parallel drop in infant mortality from 200 to 57 deaths in every thousand births.[1] Average levels of health, and food availability have increased worldwide,[2] while the real price of food commodities has declined to one quarter of the cost in preindustrial times.[3] Education has increased globally with an associated increase in adult literacy,[4] facilitating improvement in the functioning of civil society and allowing increased participation in democratic processes.[5] Economic improvements have also been brought about by the industrialisation of the developed world, with the average person earning more and working less.[6]

While these aggregate measures show significant improvements in human welfare from preindustrial times to the present, progress has not been uniform either within or between countries, and industrialisation has universally come at a steep environmental price. Alarming statistics associated with the widening gap between the rich and the poor tell us that neither wealth distribution nor environmental equity have been products of industrial development, and in fact the situation with regards to equity is worsening in many countries. For example, the number of people living on less than US $1 per day, defined by the United Nations as absolute poverty, has reached 1.3 Billion.[7] Life expectancy has regressed in 18 countries, mainly as a result of deaths related to AIDS, and at least 50 countries have lower per-capita incomes today than they did twenty years ago.[8]

Industrial metabolism is the fundamental overarching factor which links humans and societies as agents of global environmental change. By participating in the industrialised metabolism of the developed world, every person every day is an agent of environmental and social impacts that are beyond the understanding of current scientific knowledge. Society's industrial substance abuse since the beginning of the industrial revolution has led to a deep cultural and physical dependency on non-renewable sources of energy, and unsustainable flows of material through the earth's biosphere. Thus we find that the ecological basis of our industrial lifestyles, along with its capacity to recover, is becoming systematically overwhelmed by anthropogenic excrement.

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[1] Goklany, 2003
[2] ibid.
[3] World Bank, 1999
[4] ibid.
[5] United Nations Development Program, 1999
[6] Goklany, 2003
[7] ibid; United Nations Development Program, 1999
[8] Goklany, 2003

Typical everyday consumption in the developed world involves the liberation of toxic metals and carcinogenic carbon chains that have been locked away in the mineral oxide or sulphide matrices of the earths crust for prehistoric eons. Every industrial minute, thousands of tonnes of substances that have the capacity to irreversibly alter global climate are freed from the inertia invested in them over millennia by the earth's self-regulating biogeochemical cycles.[9] Every revolution of a motor, or flick of a switch causes these elements to be oxidised, mixed, exothermically reacted and exhausted into the global air shed so that we can be provided with mobility or comfort for a fleeting moment.

Even the unimaginable array of naturally occurring substances and their myriad combinations do not satisfy the capitalist industrial desire to provide and consume. New chemicals are constantly conceived and synthesised in the effort for industrial efficiency and these toxics are inevitably released into natural systems that have no assimilative capacity for the alien species. Many of these chemicals are sprayed directly onto the crops that we eat, or worse, onto the soils that forms the mineral medium for the life-supporting biosphere of our planet. Here they persist and relentlessly bioaccumulate, ultimately and obviously ending up in the food and material chains that provide sustenance for the human species and the anthropogenic techno-metabolism that planet Earth has become.

The non-linear systems that govern the self-regulating global elements of atmosphere, oceans, and living biota are impossible to predict with scientific accuracy. Many scientists fear that positive feedback loops of environmental change have already been triggered with unknown consequences for intercontinental oceans, atmospheric systems, and biodiversity. Thus we see an entire population of 17 000 pacific islanders requesting environmental refugee status from the Australian Government as they flee the affects of climate change on the coral atolls they have called home for thousands of years. And thus we see remote Inuit populations poisoned by their traditional food sources as global distillation and fractionation processes systematically gather and concentrate volatile chemicals in the fatty tissues of polar wildlife, including the estimated million tonnes of polychlorinated byphenyls (PCB's), one of the most toxic chemicals known which have been released into the environment since the sixties.[10]

As consumer agents of a systematically malignant but outwardly profitable industrial metabolism we find our lifestyles and our realms of understanding removed from the consequences of our daily actions by the very design of that system. Thus a typical American mother is surprised when analysis of her own breast milk reveals traces of over one hundred synthetic endocrine disrupting and carcinogenic chemicals.[11] If the same mother eats fish regularly, or at all during pregnancy, the chances of her female child developing breast cancer later in life are further increased.[12] A typical human male has to live with untold amounts of these untested toxics circulating through his bloodstream and accumulating in his fatty tissue during the length of his life. A female however has the sacrificial advantage that her lifetime's accumulation of these substances is largely transferred to her unborn child.

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[9] For example, 3.4 billion gallons of crude oil are burned every day (Valdmanis, 2003)
[10] Pearce, 1997
[11] Natural Resources Defence Council 2001, see also McGinn, 2000
[12] Brown, 2001

Introduction

Conventional industrial systems operate by extracting resources from the earths crust or the biosphere, processing those resources into products that are useful and therefore profitable, and then returning the materials back into the biosphere in a degraded high entropy state after use has ended. With the industrial revolution and rapid population growth of the 20th century, combined with the voracity of neoclassical consumer capitalism and the globalisation of production and trading systems, humans have become major biogeochemical agents. Industrial resource flows in many cases exceed in volume by several factors their natural counterparts. Global induced flows of sulphur, for example, amount to nearly three times the naturally occurring transactions of that element.[13]

Industrial material flows of a toxicity and magnitude far exceeding the assimilative capacity of natural environments now present a serious threat to the sustainability of human development. In the search for solutions to these fundamental issues we must examine our industrial systems through new lenses, and thus redefine the way we participate in, govern and conceptualise industry. What is undeniably urgent is the restructuring of our manufacturing and consumer society to reduce the effects of material and energy flows; however these changes must occur at the very point in history when globalisation, population growth, and industrialisation of the developed world are rapidly increasing those effects.

The last twenty years has seen industrial institutions locked into a sub-optimal and failing relationship of mistrust and dispute, with, and between industry, communities and the public sector. The ongoing failure of this relationship has often been described by environmentalists as representing a fundamental conflict of interest, and by economists as a political failure of resource maximisation. The dialogue of sustainability potentially provides a way forward from this traditional industry versus environment dispute, a dispute which so far has demonstrated limited capacity to provide sustainability outcomes.

Two significant foci of industrial sustainability discussion so far have been:

- The relationships between industry and the natural environment, or typical industrial environmentalism with it's associated politicisation and environmental regulation; and,
- The contributions of industry to economic growth as a prerequisite for sustainable development.

Earlier literature laments the oppression resulting from the industrial commodification of human capital and labour resources. Marx, followed by Roszack, and later, Freeman, offer (respectively) political, individual, and economic treatments of the issues relating to the vocationally degraded human condition of industrial society. Globalisation has obfuscated and shifted these industrial sustainability issues from the more visible level of domestic politics to the more remote concerns of global equity and social justice.

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[13] Grubler, 2003

Thus far, the relatively uncoordinated response to industrial sustainability has primarily directed attention towards notions of assimilative capacity, industrial efficiency, and engineering solutions to environmental impacts. These approaches have been pursued within neoliberalist management frameworks, ensuring that such adjustments to industrial development are consistent with, and contribute to, the continued profitability and growth of industrial metabolism. Hence we have seen widespread governmental encouragement of industry to adopt the broad goals of cleaner production and eco-efficiency – the simultaneous improvement of economic and ecological performance. These approaches have produced mixed results, and so far limited contributions to sustainable development in the sense that the industrial metabolism of the developed world continues to have an increasing impact on ecological, and by many measures, social sustainability parameters.

Many harmful industrial point source emissions, for example Chlorofluorocarbons (CFC's) and Polychlorinated Byphenyls (PCB's) have been successfully curbed by international and national government action mandating better environmental management – mostly manifesting in the form of technological and end of pipe engineering solutions. On the other hand, the industrial metabolism of the developed world largely continues to develop in ways that increase the overuse of non-renewable resources, the unsustainable flows of materials through industrial economies, and the climate-changing emissions of known greenhouse gasses into the international air-shed.

As new scientific understanding consistently reinforces the urgency to change the industrial development patterns of the past and present, it is clear that revised and multi stakeholder approaches to development and decision-making are required in response to present and future industrial sustainability issues. Any politically workable approach to sustainability must remain within the culture of pragmatism and incremental change that characterises industrial development patterns today. However, to deliver sustainable outcomes such solutions must bring with them the potential to articulate a foundation, and when required a mechanism, to facilitate the fundamental changes which will be necessary to move to a sustainable trajectory of industrial development.

A vital part of the next industrial revolution will be the rebuilding, and systematic strengthening of the failing relationships between industrial institutions, the public sector, and the community. These relationships will need to be fostered, reinforced, and depoliticised within two significant spatial spheres. Industry associations at a national and international level will be required to significantly strengthen their individual and collective responses to global sustainability issues, through capacity building in the form of cooperative relationships between government, industry associations, and other non-government organisations. Significantly, industrial sustainability issues must also be addressed at a regional level, where communities are most directly engaged in industrial production through employment, amenity, and environmental and social impact.

This paper documents and explores some potential examples of such a phase-change in industrial development patterns, which may be evolving by a combination of design and default. The paper also explores how the evolutionary development of these examples can be informed and understood by the powerful metaphor offered by an ecological approach to complex system dynamics. Industrial ecology, or the application of an ecological metaphor to inform the design of industrial systems, will therefore be used as a platform to examine industrial metabolism in several new ways.

The paper critically outlines current industrial ecology approaches and applications of the ecological metaphor to industrial systems, with reference to some practical examples, including the Kwinana Industrial Area in Perth Western Australia. A narrow mechanistic approach to the modelling of resource flows through simplified and isolated components of complex systems is shown to be lacking in its capacity to deliver a model for the sustainable restructuring of industrial systems. The ecological metaphor is therefore explored and expanded in its capacity to deliver a robust model for addressing the complex sustainability issues associated with industrial metabolism.

By drawing from several different models describing organisational and development characteristics of ecological systems, this paper advocates a deeper and more complex understanding of ecology in its application to anthropogenic systems. The conceptual basis for addressing industrial sustainability issues will also be expanded, to examine the developmental and organisational ecology of the relationships between institutions and stakeholders of industrial development and decision-making. This paper therefore explores industrial ecology as the ecology and evolution of stakeholder relationships affecting industrial development processes, as well as the ecology of industrial resource flows at the complex metabolic system level.

The Measures and the Materials of Industrial Metabolism

The basis of understanding industrial (or ecological) metabolism from a mechanistic or technical perspective involves the analysis of material flows from resource extraction to final waste disposal. Material flow analysis can be used to assess the pressure of materials throughput on the carrying capacity of natural systems, based on laws of thermodynamics and the conservation and entropy of energy and matter.[14] In this context, analysis of material flows can be considered complimentary to economic evaluations of material scarcities and supply and demand analysis. Material flow analysis techniques are particularly compatible with economic analysis provided by the emerging disciplines of environmental and 'triple bottom line' economics that seek to account for unpriced 'externalities'.

Material flow analysis can be used to draw attention to both quantitative and qualitative aspects of industrial material flows, and can be applied at any scale where the transfer of materials occurs. The total materials required to produce, for instance an aluminium can, includes the aluminium in the can itself, plus hidden material flows, such as the amount of virgin ore moved to produce the aluminium, and the materials required in transporting the product during its various life stages including disposal or recycling. These 'hidden flows are termed the ecological rucksack[15] of an item and can represent many times the amount of material in the product itself.

On a broader spatial scale, material flows can be studied at a global level, or at the level of nations, continents, or economies. Little qualitative analysis has been undertaken at this level, however quantitative mass-balances have been estimated for a number of countries. This gives rise to the calculation of the total materials requirement, or TMR of a country.

As we would expect of an economy that is based largely on primary production and resource exploitation, we find that the TMR of the Australian economy is very high by world standards, and rising. CSIRO[16] estimates that in 2000, the total material requirement of the Australian economy per capita was over twice that of the next highest measured country, the USA, and over six times that of Japan. Trends were also indicated by this CSIRO analysis, which showed Australia's total material requirement rapidly increasing, while that of the United States displayed a downward trend. Figure 1 (Below) shows the estimated total material flows induced by the Australian economy with comparisons from other selected countries.

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[14] Bartelmus, 2002.

[15] Brigenzu, 2003; Fussler and James 1996

[16] Turner and Poldy, 2002

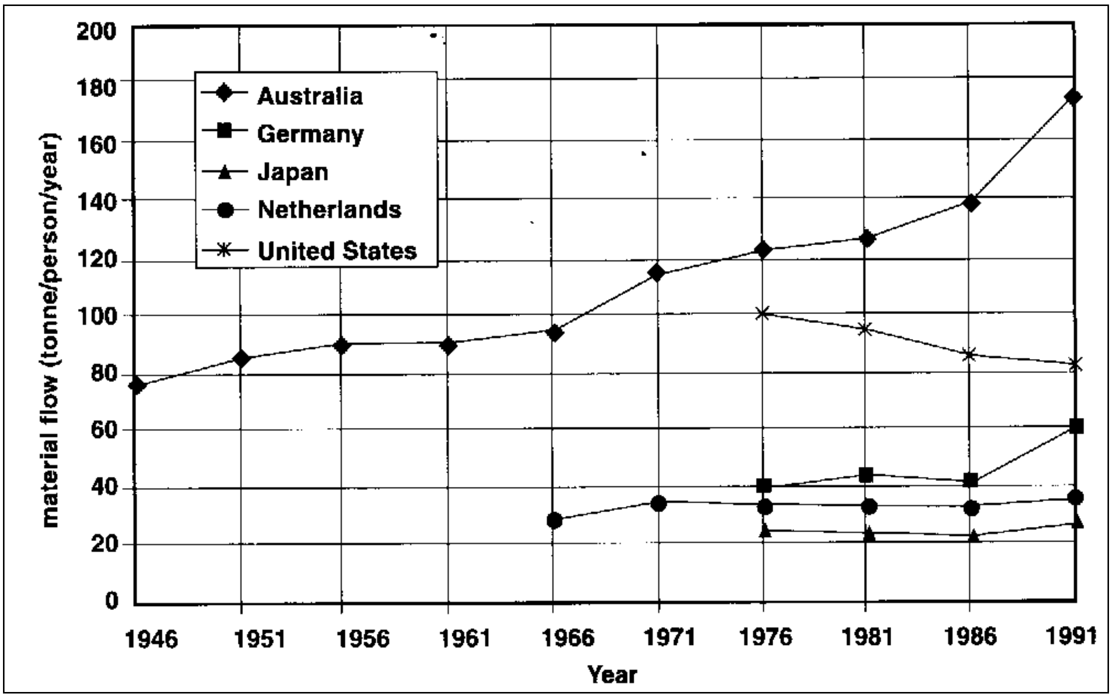

Figure 1: Australian total material flows with selected comparisons from other countries.

Source: Yencken and Wilkinson (2000) p. 95, after Poldy and Foran (CSIRO), (1999)

The aim of dematerialisation at the broadest level is to reduce the material intensity of an economy by decoupling material flow increases from economic growth. This ratio can be measured when we calculate the amount of materials required by an economy, per unit of gross domestic product. Figure 1 shows that the Material intensity of the Australian economy is very high, but by how much do we need to reduce the volume of these material flows in order to become sustainable? In other words, what is the dematerialisation stretch goal of the Australian economy?

While little work has been undertaken to answer this question at the level of the individual countries, much interest has arisen surrounding proposed increases in resource productivity for industrialised countries in general. A factor of 10 was proposed by Schmidt-Bleek in 1992 as a general goal for the increase of resource productivity in industrialised countries over 50 years to achieve a sustainable state of industrialisation and halve the global resource requirements.[17] A more moderate factor four has been proposed by Weizsacker *et al* (1995) as a dematerialisation goal, which translates into the agreeable notion of 'doubling wealth while halving resource use.'[18] Since the mid 90's, the World Business Council on Sustainable Development (WBCSD) has returned to the ambitious target of a 10-fold reduction in the consumption of resources (factor 10 dematerialisation), combined with a 20-fold increase in resource efficiency by 2040.[19]

[17] Bringezu, 2003
[18] Weizsacker, Lovins, and Lovins, 1998
[19] Trewin, 2003

In their popular recent book, Weizsacker *et al* document many examples where individual components of developed economies, such as a particular industry, product, or consumer, have successfully achieved a factor four (or greater) reduction in resource use. It is yet to be demonstrated how these individual reductions in resource intensity would translate into an overall reduction in resource use through an entire national or global economy. Later in this paper, attention will be given to why this necessary outcome may prove elusive to the eco-efficiency agenda suggested by Weizsacker *et al*.

Factor X estimates for the required increases in resource productivity in industrialised countries may be a useful tool for the communication of concerns regarding the sustainability of industrial resource flows as well as the magnitude of action required as a solution. In the Australian economy, where it is clear that resource flows are the highest in the world per person, at least by volume, the factor reduction required to achieve resource sustainability would be significantly higher than the average factor reduction proposed for the developed world. This is another way of saying that the resource flows associated with the Australian economy are significantly less sustainable than those associated with other industrialised economies, and therefore the magnitude of change required to achieve resource sustainability will be correspondingly greater.

Factor X though, may be an oversimplification of the highly complex economic, political, and institutional problem that is faced by the stakeholders of Australia's sustainable resource future. While the flows of some substances may be well within the ecological carrying capacity of Australia's ecosystems, other (critical) substance flows through nature will have to undergo a reduction to zero, or an infinite factor reduction. For example, "[a]ccording to 8 out of 10 of the world climate models, to stabilise CO_2 in the atmosphere at 350 ppmv (which is most likely too high by at least 50 ppmv if ecological sustainability is to be achieved) it will be necessary to:

- bring down world industrial and agricultural CO_2 emissions to **zero** (net) over the next 60 years; and
- pull CO_2 out of the atmosphere on a net basis for the next 80 years by creating carbon sinks."[20]

The material intensity of an economy alone therefore, does not form a reliable indicator of the material **sustainability** of that economy. While all material flows have associated ecological impacts,[21] different material flows vary considerably in their capacity to cause ecological damage. For example, the 4.7 kilograms of cyanide used to produce a single ounce of gold by a mining firm in Western Australia has a far greater ecological, and therefore also cultural impact, than the 42 tonnes of waste rock moved in the production of that same ounce.[22] Therefore an agenda of industrial dematerialisation alone will not necessarily reduce the ecological and social impact of industrial material flows. A sustainability assessment of Australia' industrial metabolism thus requires analysis of critical substance flows as well as total material throughput.

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[20] Sutton, 2001
[21] Socolow *et al,* 1997
[22] Ramsey, 2003

Qualitative material flows analysis considers the toxicity and capacity for environmental damage associated with a particular material flow. Three qualitative categories have been suggested by the World Resources Institute for the assessment of materials flow through industrial metabolism.[23] The **mobility** of a material describes the dynamics of that material's movement in the environment, while the **velocity** of a material is a measurement of the length of time the material remains in the economy or in service. Materials remaining in service for many years have a lower environmental impact than for example, non-recyclable packaging materials that typically leave the economy the same year that they enter. Thirdly, the **quality** of materials represents the nature of the interaction of those materials with the environment. Interaction characteristics of materials include toxicity, and whether the materials biodegrade or accumulate, as well as the length of time that the material persists in the environment.

Just as quantitative estimates of total material requirement have only been undertaken for a handful of countries, the qualities are known of only a very small proportion of the material flows induced by industrial society. Another measure that can be used to compare the resource sustainability of industrial economies, taking into account the qualitative and quantitative aspects of material flows as well as other factors, is ecological footprint analysis. The ecological footprint is an approximation of the total land area required to support a particular person, activity, or development, reflecting the eco-capacity of resource availability and waste assimilation. As more estimated variables are combined together in a single measure, the accuracy of that measure is reduced, however, ecological footprint analysis can provide a useful standard for the resource sustainability of industrial nations. Figure 2 (below) provides a graphical comparison of the ecological footprints per person in various countries including Australia.

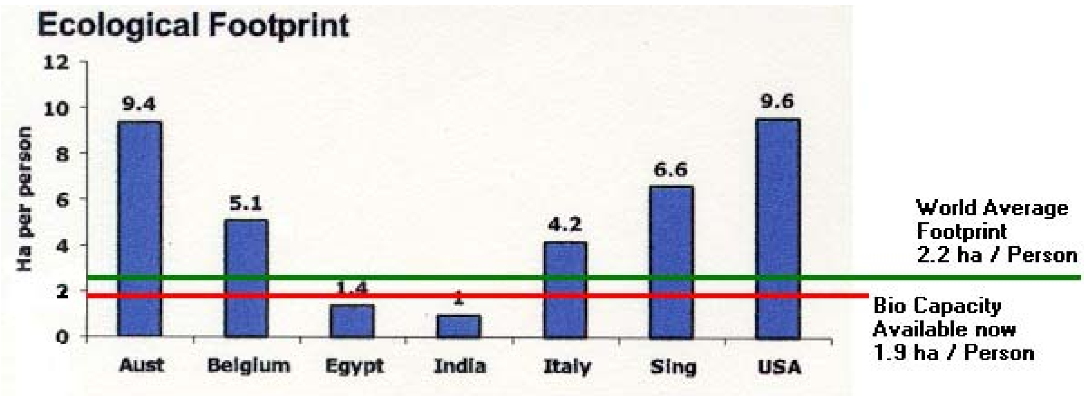

Figure 2: Comparison of Ecological Footprint in Selected Countries

Adapted From: Greg Trewin, NSW Environmental Protection Authority, 2003, and Dr. Joe Herbertson, 2002

As we can see in figure 2, the ecological footprint of an average Australian is very high by world standards. Each Australian requires approximately 9.4 hectares of land

[23] Yencken and Wilkinson, 2000

area to sustain their level of resource consumption. The world average ecological footprint is about 2.2 hectares, but even this exceeds the sustainable bio-capacity of the earth, which was about 1.9 hectares per person in the year 2000 (represented by the red line in figure 2). The trend for the global average ecological footprint per person is that it is rising with the industrialisation of the developing world countries. As a result of population growth, it is predicted that by 2050, the available bio-productive area per person will be reduced to approximately 1.2 hectares per person.[24] This is regarded as the long-term sustainable ecological footprint that will need to be the target of reducing the average global footprint by 2050.

The high ecological footprint of Australia's population indicates that the massive amounts of material required by our national economy are not in fact as environmentally benign as we would like to think. It should be noted that a large proportion of the TMR for Australia is in the form of non-critical substances whose quantities are high but qualitatively have a relatively contained ecological impact, such as mining overburden and soil moved during agriculture. These material flows do not enter Australia's economy as products, and are thus termed 'hidden flows' or 'ecological rucksacks.' The 'ecological rucksacks', or hidden flows of primary production burden the environment locally by devastation of natural habitats, groundwater contamination, landscape changes and so on.'[25] For example, in the Western Australian wheatbelt, industrialised agriculture is causing severe degradation of arable lands due to irreversible salinisation.

In many cases however, especially in developed economies such as Australia, where environmental regulation is significant and primary producers have various environmental management regimes in place, these large hidden flows account for a lesser proportion of ecological impact than the much smaller flows of critical substances that enter the economy. For example, in the North of Western Australia, during the shifting and processing of the 50 tonnes of rock required to produce a piece of gold about the size of a $2 coin, seven thousand litres of water is used, half a tonne of greenhouse gasses and nearly 5 kilograms of cyanide are released into the environment, and the equivalent of an average Australian household's energy requirement for 61 days is used.[26]

Primary production is also intrinsically linked to secondary production in terms of its associated ecological impact. The Australian aluminium smelting industry for example, uses 14% of Australian electricity production, and the industry represents ~9% of Australia's greenhouse gas emissions.[27] Thus, contrary to the notions of some institutions, primary and associated secondary production in Australia is contributing significantly to the unsustainable resource flows associated with, and hidden within the economy of this country.

Thus we have examined some indicators demonstrating the deeply unsustainable nature of Australia's industrial resource economy, and indeed, the global industrial metabolism. The evidence we have seen resonates with Tibbs statement of over ten years ago, adding urgency to his environmentally motivated concerns:

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[24] Herbertson, 2002
[25] Brigezu, 2003
[26] Ramsey, 2003
[27] Herbertson, 2002

> 'The ultimate driver of the global environmental crisis is industrialisation, which means significant, systemic industrial change will be unavoidable if society is to eliminate the root cause of environmental damage. The resulting program of business change will have to be based in a far-sighted conceptual framework if it is to ensure the long-term viability of industrialisation, and implementation will need to begin soon.'[28]

As such, Senge and Caretedt note that industrial society is 'at a crossroads':

> 'We can either continue moving ever more rapidly in a direction that cannot be sustained, or we can change. Perhaps, no time in history has afforded greater possibilities for a collective change in direction.'[29]

The remainder of this paper will examine mechanisms to facilitate change, to redirect industrial metabolism along a development trajectory that sustains the improvement of human society and the vital ecological condition of the earth on which we depend.

[28] Tibbs, 1992
[29] Senge and Carstedt 2001

Industrial Ecology – A Mechanistic Perspective

Industrial Ecology is an emerging field of study that aims to improve the sustainability of industrial metabolism by applying an ecological metaphor to the design of industrial systems. Industrial ecologists attempt to address the need for an urgent yet practical revision of conventional industrial system design. Proponents of this vision draw from the operational characteristics of natural systems, as they are conventionally understood by the science of ecology, to inform the development of a more sustainable and ecologically benign industrial metabolism. This ecological metaphor has been applied most significantly by industrial ecologists to the mechanistic modelling of resource and material flows induced within the industrial components of anthropogenic metabolism.

In this sense, conventional industrial systems are often characterised by linear and consequently unsustainable resource flows with various phases of extraction, processing, use, and disposal. By contrast, systems of industrial ecology are designed to operate around quasi-cyclical or closed-loop resource flows. Just as in ecological systems, this vision of industrial ecology allows the 'waste' of one process to become the 'food' or raw inputs for the next.[30] This of course is not by any means a novel idea, in fact, recycling and industrial symbiosis has occurred since the inception of industrial development.[31]

A focus on the technicalities of resource interaction within natural systems gives rise to the identification of resource flow networks such as those found in the cells of living organisms. Figure 3 (below) shows the individual components of a living cell functioning in an interconnected fashion, linked by a complex network of information, matter, and energy flows.

[30] Mcdonough and Braungart 2002
[31] Desrochers, 2001a; 2001b; Erkman, 1997

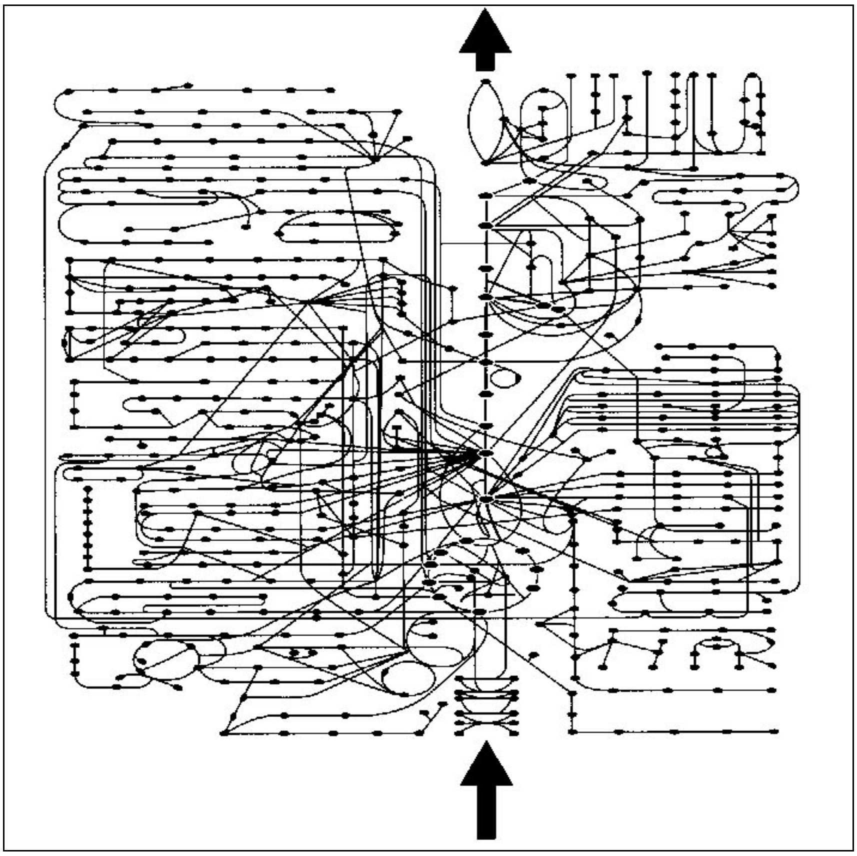

Figure 3: Cell Metabolism

Source: Bablon, A. 2003

Raw materials, or nutrients enter the cell at one point, while waste is expelled at the other. According tho this mechanistic and simplified modelling of a particular sub-component of an ecological system, the components of the cell are thought to be located and connected in such a way as to represent close to the maximum entropic efficiency obtainable in performing the vital functions required for the cell to survive. It is one suggestion of this paper, that if a broader and deeper understanding of ecological systems is employed, this assumption regarding the concept of efficiency may not in fact reflect the qualities of nature which are most conducive to system sustainably.

The preoccupation by industrial ecologists in modelling resource interactions within isolated biological system components, such as the cell described above, represents a mechanistic and reductionist understanding of natural processes. Consequently, the application of this rudimentary modelling of biomimetic design principles to industrial systems has evoked a wealth of literature focussing on technology driven engineering solutions with the primary aim to increase the efficiency of industry. Thus the approach focuses primarily on the infrastructure and technology required for pollution reduction and waste exchanges within and between the industrial components of induced resource flows.[32]

[32] Schlarb, 2001

Despite the claims of some authors, this technical engineering application of biomimetic design does little to promote a departure from the ideology which many commentators believe is the root cause of unsustainable industrial development – that of the Baconian scientific ethic of mastery of man and his machine over nature.

An industrial estate situated near the town of Kalundborg in Denmark, is by far the most well studied example of industrial ecology from the technical engineering perspective, with an example or case study of the Kalundborg industrial estate appearing in almost every example of technical industrial ecology literature. The Danish example represents a particular type of eco-industrial estate based on industrial symbiosis and resource exchange. Figure 3 (Below) illustrates the network of 8 industrial firms that comprise the Kalundborg industrial estate. At the centre of the resource exchange network is Asnaes, ironically Denmark's only remaining coal-fired power station. Figure 4 (below) represents the system components of the Kalundborg industrial estate connected by a simple network of resource exchanges.

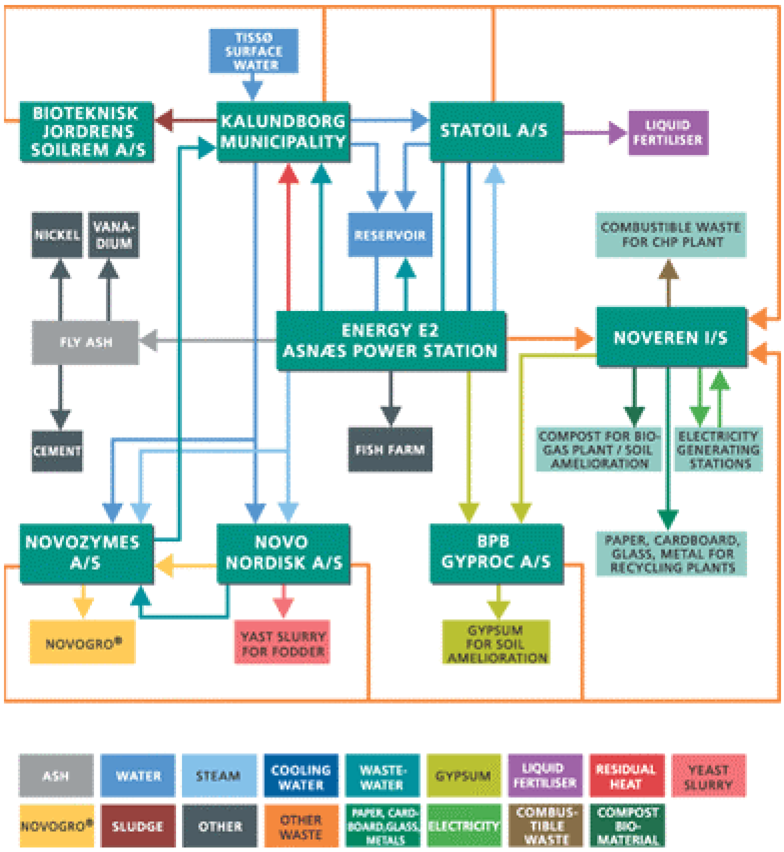

Figure 4: Industrial Symbioses in Kalundborg

Source: Kalundborg Region Industrial Development Council, 2003

The Kwinana Industrial Area in Perth Western Australia also demonstrates a significant level of industrial symbiosis. While this complex resource exchange network has not attracted attention from industrial ecologists, it represents an internationally significant example of industrial symbioses. The Kwinana estate is of a much greater overall size than the Danish example, comprised of 28 heavy industries linked by an existing network of 106 resource interactions. Over a decade ago, in 1990, the then 13 core process industries occupying the Kwinana site were surveyed for existing and potential interactions.[33] Figure 5 (below) represents the 27 interactions between the core Kwinana industries at that time.

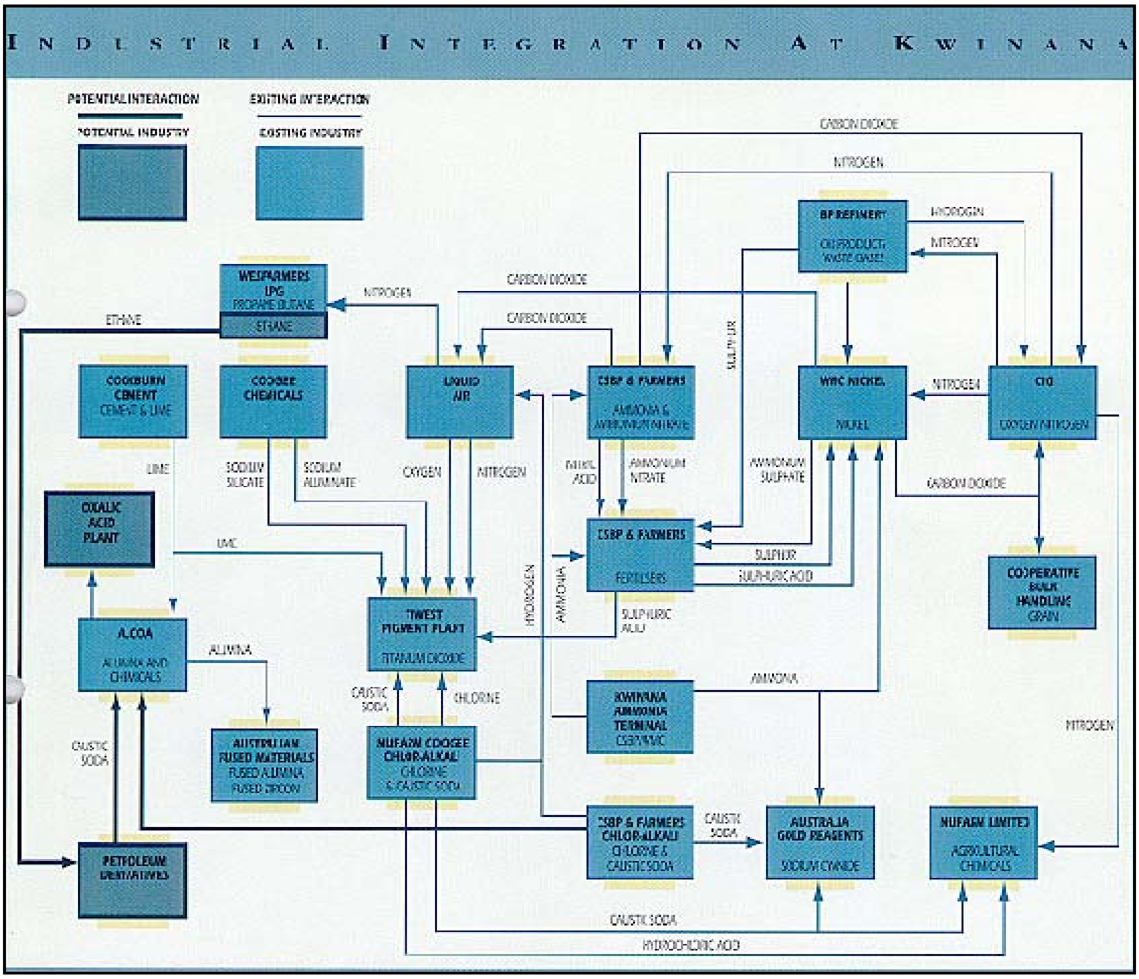

Figure 5: Industrial Symbioses in Kwinana 1990
Source: Dames and Moore, 1990

During the last decade the degree of interaction between industries in the Kwinana industrial site has more than doubled from 27 interactions among core process industries in 1990, to 68 interactions among core process industries in 2002, as well as the development of 38 additional interactions involving non core industries. Figure 6 (below) shows the total 106 existing interactions between the Kwinana industries, including the original 13 industries surveyed in 1990, as well as 8 new core process industries, and 7 service and infrastructure industries providing energy, water, and other services.

[33] Dames and Moore, 1990

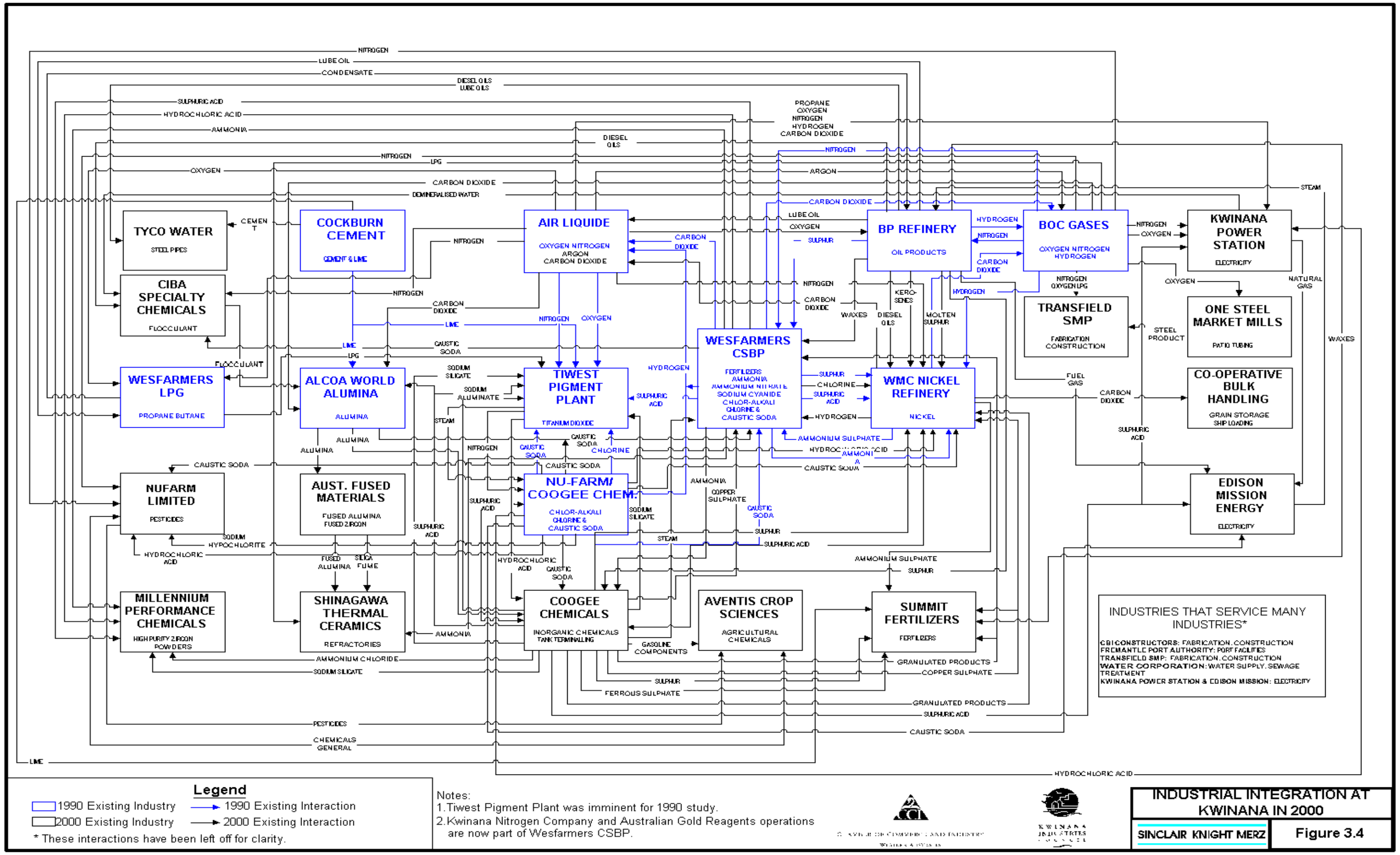

Figure 6: Industrial Symbioses at Kwinana, 2002

Source: Kwinana Industries Council *et al* 2002

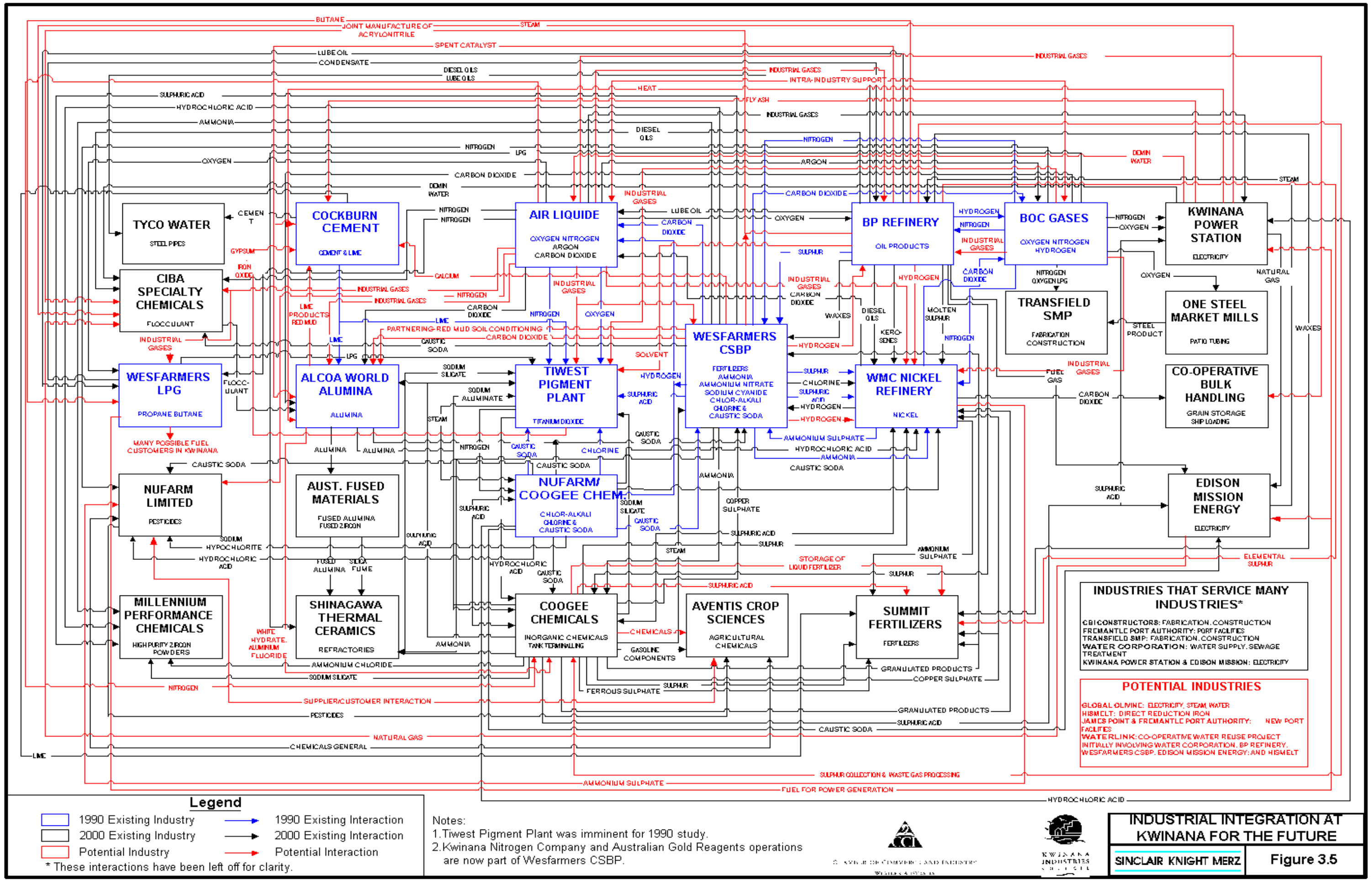

Figure 7: Potential Industrial Symbioses in Kwinana

Source: Kwinana Industries Council *et al* 2002

During an economic impact study of the Kwinana industrial area undertaken in 2002, a survey of the Kwinana industries showed that 106 existing resource interactions were in place at that time.[34] Figure 6 shows these existing interactions as blue lines indicating interactions that have been in place since 1990, and black lines indicating resource synergies that have been developed during the period 1990 – 2002. As part of the 2002 economic impact study, surveying of industries also identified a total of 104 potential synergies that have yet to be developed. Figure 7 (directly above) shows the existing interactions, as well as the 104 potential interactions indicated by red lines.

Despite the obvious interest in documenting industrial interactions in the Kwinana region as part of an economic impact study process, no mention has been given in the study as to *how* interactions were developed, or more importantly, *why* have they developed and what were the *drivers* for this development of industrial symbioses. The 2002 economic impact study of the industrial area suggests that the level of interaction between Kwinana industries has increased over time, 'reflecting increasing interdependency, and the need for greater interaction between the industries to maintain their comparative advantages in production and ensure their longevity within the Kwinana area.'[35] Conversations with representatives of the respective Kwinana industries confirm that the primary incentive to pursue resource interactions with neighbouring industries has been cost savings. This is reflected by the fact that all interactions developed to date have been profitable for the industries involved.[36]

While the development of resource interactions among Kwinana industries may be, by default, an expression of eco-efficiency, it remains unclear as to how industrial symbioses contributes significantly to an agenda of industrial *sustainability*. As illustrated earlier, it is the assumption of industrial ecology that by displaying similar characteristics to those of (inadequately understood) natural systems, industrial symbiosis is a sustainable form of industrial development. This assumption is poorly examined in industrial ecology literature. In the rare event that any explanation is given from the ecological metaphor, it is suggested that industrial symbioses may result in greater resilience to change, as well as a closer resemblance of the resource flow characteristics displayed by ecosystem components, that is, recycling, or quasi-closed loop resource flows. These contestable characteristics of ecological systems, and the models of understanding which inform them, will be examined in more detail and through a sustainability lens in the following sections of this paper.

[34] Kwinana Industries Council *et al* 2002
[35] ibid.
[36] Martin Taylor, Kwinana Industrial Council, Pers. Comm. 2003

The Ecology and Economy of Efficiency - Development Paradigm or a Path Dependency?

Efficiency is the consistent preoccupation of the well-intended agendas of industrial ecology, cleaner production, and eco-efficiency. These agendas have variously been forwarded as initiatives capable of delivering the broader objective of sustainable industrial development.[37] Improving the efficiency of industrial metabolic components in this sense would ostensibly seem consistent with the reduction in energy intensity and dematerialisation of the industrial metabolism as discussed earlier in this paper.

Economic and ecological theory, as well as recorded observation indicates however, that while industrial efficiency is undeniably necessary, it may not be the holy grail of industrial sustainability as often assumed. Paradoxically, efficiency-driven industrial innovation such as industrial ecology and eco-efficiency may in some cases act to further erode the system sustainability of industrial metabolism by allowing greater consumption and decreasing system stability. In examining the problematic understanding of efficiency that informs efficiency-driven industrial sustainability agendas, the dynamics of entropy, efficiency, and waste must be understood within the context of complex and evolving systems.

Let us first examine ecological systems for clues as to what efficiency may look like in a stable and sustainable system.

In a sedge bed ecosystem, the dominant organism, sedge, uses approximately 2 percent of the incumbent solar energy that is available to the plant. The sedge plant, however, converts this small proportion of the total available energy into carbohydrate sugars to fuel cell division and metabolic processes at a rate of up to 95 percent efficiency.[38] Homeostasis and other vital functions of the sedge bed ecosystem are maintained by the remaining 98 percent of incumbent solar energy that is not used by the sedge plant. Now compare this ecosystem energy metabolism to the energy flow characteristics of industrial metabolism. Industry extracts approximately 95 percent of the available energy in a fossil fuel ore body such as a coal seam or oil field,[39] but that energy is typically used at an efficiency rate of 1 percent as electricity,[40] and between 1 and 3 percent efficiency to provide the service of personal mobility.[41]

So here we see two kinds of efficiency at work. The first kind is related to how much of a resource is NOT used, this can be called *extrinsic* efficiency. The sedge bed has evolved to leave 98 percent of the available energy resource for other ecosystem functions, such as the maintenance of homeostasis, thus it is *extrinsically inefficient*, wasteful even. By comparison, industrial metabolism leaves 5 percent of the available fossil fuel energy for the maintenance of homeostasis. Unlike nature, industrial metabolism is *extrinsically efficient*, and thus we are altering the homeostasis of our ecosystem, as witnessed by a rapidly changing climate.

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[37] For example, Australia and New Zealand Environment and Conservation Council 1998; Western Australian Sustainable Industries Group 2001; see also Day 1998
[38] Fricker, 2003; Knox *et al* 1999
[39] Coal Industry Advisory Board, 2002
[40] Fricker, 2003, Fussler and James 1996
[41] Fussler and James 1996

As we relentlessly pursue efficiency in an industrial system, we have the effect of increasing the *extrinsic* efficiency of that metabolism, thus increasing material and energy throughput, and eroding the stability of ecosystems through denying the entropy of homeostasis. Even when our well-intended efforts are directed at improving the *intrinsic* efficiency of industry by building more efficient cars, production processes, or power plants, this is almost invariably translated into increases in the *extrinsic* efficiency which is the cause of industrial unsustainability. To find out why this is the case, we must turn to the discipline of economics, and the Jevons Paradox.

The Jevons Paradox is another way of explaining that, because of the natural inbuilt maximisation tendency of the market, *intrinsic* efficiency of production will always be translated into the *extrinsic* efficiency of consumption, resulting in increased resource use. The only time when this does not occur is where the externalisation of environmental costs results in a failure of the market to recognise efficiency at all. This is demonstrated in situations where recycling imposes greater production costs than the use of use virgin products.

The Jevons Paradox was first realised by a coal-mining engineer, William Jevons in 1860s Britain, when it was thought that coal was running out. There was a drive to develop more efficient combustion processes to conserve coal supplies, as current processes were highly inefficient. What Jevons realised was that as efficiency increased in converting coal to useable energy, the costs of producing that useable energy would decrease, this would allow an increase in energy consumption, and thus an increase in the demand for coal.[42] So where industry can produce something more efficiently, it can be produced more cheaply, and therefore more of it will be sold, often consuming more resources instead of less.

Many examples exist now where efficiency increases have led to increased consumption and a parallel increase in resource use.[43] In highly inelastic markets, where a small price drop leads to a massive increase in consumption, the savings resulting from a modest efficiency gain can result in a tenfold increase in consumption and a relative increase in the draw and flow of resources.[44] Micro-economically, as a firm produces products more efficiently, overheads are reduced, and prices to the consumer are reduced as a function of competition. Macro economically, as production becomes more efficient in general, economic growth is accelerated, and consumption of resources per person increases. In the United States, Japan, and Germany, material intensity as a measure of GDP has reduced by approximately 20 to 30 percent over the past 20 years, however, during the same period, the evidence shows that the total use of materials in these countries has increased by 27.7 percent.[45]

Some examples exist where environmental benefits have resulted from efficiency driven development in the case of specific environmental problems. One case is the reduction in SOx emissions from coal burning. A significant reduction in energy demand ‘growth rates’ also resulted from energy efficiency gains in California in the

[42] Fricker, 2003
[43] ibid.
[44] Williams, 2003
[45] Day, 1998

1970's, however, the net use of energy during this time still showed increasing consumption.[46] These isolated cases demonstrate that in some situations, efficiency driven development such as industrial symbiosis may help buy some time.[47] 'The benefit (if any) of specific efficiency increases may depend on the time scales of rebound, Jevons' effect, and many other social and economic factors.'[48]

So, both the ecological metaphor, and economic observation tell us that efficiency as we have been pursuing it, is not in fact a complete means to achieve a more sustainable resource economy. While intrinsic efficiency is a characteristic of the sustainable sedge bed ecosystem, the Jevons Paradox demonstrates that driving the intrinsic efficiency of industrial systems will not necessarily lead to increased resource sustainability. What must be done then is to reduce the extrinsic efficiency of industrial metabolism. If this is done by government intervention, for example, by placing a cap on the amount of coal which can be extracted each year, the effect will still be to drive intrinsic efficiency – firms will have to use less, as supply becomes scarce, but the Jevons Paradox will be averted by price signals acting to regulate the market instead of expand it.

Placing a cap on, for example, the amount of coal allowed to enter the market in a specified time frame would appear completely counter intuitive to growth imperative neoclassical economic management. This may however be an incorrect conclusion. In the case of fossil fuels, for example, climate change, followed by resource scarcity will inevitably lead to a carbon-constrained economy. Reducing the availability of these resources sooner, rather than later would have the effect of preparing the energy economy for change, as well as cushion the shock of carbon constraint on the Australian economy. Driving a reduction in the extrinsic efficiency of industrial metabolism by limiting flows into the economy of those resources that are unsustainable by nature of their quality or quantity, may not necessarily mean strict regulation. Demand-side economic management (DSM) techniques can be applied at many stages through the lifecycle of a product or material.

DSM initiatives are supported by the actual measured sources and dynamics of environmental pollution resulting from industrial production. Consumption related releases of key substances have been shown in several studies to dominate production related releases,[49] suggesting that management of consumption demand rather than production efficiency will have a greater effect in terms of pollution reduction. DSM techniques have largely been applied to avoid environmentally and economically expensive supply investment by managing the level and/or timing of demand.[50] The situation now exists however, where innovative utility companies and public sector institutions use demand management as a tool to reduce real or projected demand for existing services, as the environmental and social costs of supplying those services increase. Demand management of fossil fuels, for instance could be applied at the first sale of the crude oil, then at various stages as the product is refined and on-sold, and then at the final sale before consumption. These techniques have been employed with significant economic benefits for many years in the electricity industry where the

[46] Krishnan 2003, see also Heusemann 2003
[47] Heusemann 2003
[48] ibid.
[49] Lifset 2000
[50] Marvin 1995

management of daily electricity demand curves is necessary to efficiently operate large centralised facilities.[51]

Demand-side management is also being employed with great success in the transport industry, with the Western Australian TravelSmart example of travel demand management (TDM) consistently reducing car trips by 10% in the localities where it has been employed. Other examples include the demand-side management of tobacco products for health reasons, and the recent demand side management of water in Perth, taking the form of public education campaigns linked to water restrictions preventing overuse of sprinklers and garden irrigation.

In these cases, regulation has been an important component of the demand management technique, however, equally important has been softer approaches such as information and education campaigns, or their strategic removal, as with cigarette advertising. In any case where demand-side management of a 'necessity' such as transport, or energy is employed, it will be important to match the reduced consumption of an unsustainable product, for example, energy derived from the combustion of fossil fuels, with the supply of an alternative such as reasonably priced renewable energy. Thus a combination of demand and supply side management may provide a powerful policy tool for promoting a transformation to a sustainable resource economy.

Take-back policies for consumer items have the advantage of relatively easy implementation as well as successful precedents in European countries; however this technique is limited where the majority of consumer goods are imported as in the Australian economy. Take-back policies also do little to promote product efficiency and durability, as the main focus is to improve manufacturing processes to encourage recycling. While recycling reduces the draw on virgin resources, it does not curb total resource flows, and is often energy-intensive, so the cycling of materials multiple times through the economy represents a different, but equally harmful impact on ecological systems, especially where resource economies and recycling loops are driven by fossil fuels.

Take-back policies represent a small step in the direction towards a service economy where genuine resource stewardship and the separation of technical and natural nutrients may become a reality. A significantly dematerialised economy would result from the purchase of services such as personal mobility or floor covering, rather than products such as cars and carpet. This transition provides a mandate for firms to increase the durability and longevity of service items representing a significant shift from the unsustainable throwaway resource economy of today, without a parallel reduction in standard of living or economic growth.[52]

Significant reductions in the entropy invested in waste would also result from a systematic separation of 'technical nutrients,' such as plastics, chemicals and metals, from 'ecological nutrients' such as natural fibres, wood and paper products throughout the industrial metabolism.[53] Current industrial practices combine these

[51] The E7 Network of Expertise for the Global Environment 2000
[52] For a detailed explanation of the service economy, see Brown, 2001; Weizsacker, Lovins, and Lovins 1998
[53] McDonough and Braungart 2002

‘foods’ into high entropy waste, rendering the nutrients useless to either the technical metabolism or the ecological system, and disrupting homeostasis by systematically increasing entropy and dismantling the inertia of the earth system invested over time by nature. It will be necessary, however to avoid the serious intellectual mistake of assuming that it would be sustainable, or even possible to completely separate the technosphere from the biosphere of the earth. The fact that humans cannot live on technical nutrients alone provides an inevitable contradiction to the assumption that technical nutrients and biological nutrients can be kept entirely separate. Further, the built resource management systems that have been politically and environmentally sustainable (enduring) over very long periods of time, such as irrigation systems in rural Philippines and forest management systems in Japan, have worked in close integration with the natural systems that form their basis.[54] The policy challenge will be finding mechanisms to promote the transition to an economy where services are traded rather than goods, and technical metabolism is benign to the operation of ecological systems.

On a philosophical note, recognition of the limitations of industrial efficiency agendas may promote an acknowledgement that although consumption leads to an increased standard of living; it might also in some way be associated with a decreasing quality of life. This situation is well illustrated by the doubtful personal mobility gains associated with private vehicle ownership. When all the time spent by an average American on their motor vehicle is added up, including earning money to pay for it, fuel it, service it, paying taxes for the infrastructure to drive it, washing it, waiting in it and for it, etc. etc., it calculates that that average American only achieves a transport speed of 5 kilometres per hour.[55] In this way, the American spends the same amount of time on personal mobility per kilometre as people in ‘underdeveloped’ nations without access to cars.

As we begin to understand more about the concept of efficiency, and the natural maximisation tendency of markets, it is instructive to examine some of the reasons why industrial metabolism, evolving after the selection pressures associated with millions of trades per second, does not display efficiency in the same way that ecological systems do. The Jevons Paradox partly answers this question, but a purely economic modelling of efficiency in production systems overlooks the fact that the market operates within the constraints of culture and infrastructure. To understand the profound implications of these factors on industrial innovation, we must examine the phenomenon of path dependant development.

Usually applied to the modelling of technology and its uptake, but equally applicable to the technology of development itself, path dependencies arise when development becomes ‘locked into’ an inefficient, or in this case unsustainable form. The most widely recognised example of a path dependant technology is the curious example of the development of the QWERTY keyboard.[56] This keyboard format was developed during a time when manual typewriters would jam easily if letters were struck too fast in succession. The QWERTY keyboard was thus developed to prevent fast typing – by placing the keys in such a way that it was difficult to type fast and jam the keys.

[54] Ostrom, 1994; Hukkinen, 1999
[55] Illich, 2000
[56] Freeman and Soete, 1997

Now, over one hundred years later, we still use the QWERTY format as people know how to type using this layout, and computer manufacturers give us little other option.

Thus we can see that there is both a cultural (learned), as well as an infrastructure (built) dimension to the phenomenon of path dependent development. Private vehicle ownership in cities, and the use of fossil fuels for energy are two other unsustainable path dependencies into which industrial development remains locked in both a cultural and an infrastructural sense. A model of sustainable development then must address the dual objectives of urgently dismantling the existing unsustainable path dependencies associated with 20^{th} century industrial economies, as well as displaying sufficient flexibility and diversity to avoid new path dependencies associated with future technologies or development trajectories. Ironically, this must be achieved through mechanisms that are acceptable within the culture of policy pragmatism and incremental change that currently act to perpetuate those path dependant forms of development.

Industrial Sustainability

Given the deeply unsustainable nature of Australia's resource economy, simply developing in a more sustainable way than has been the case in the past, i.e. improving the economic, social and environmental outcomes of industrial development; will not suffice to achieve resource sustainability. In this sense, '[s]ustainable development alone does not lead to sustainability. Indeed, it may in fact support the longevity of the unsustainable path.'[57]

What is needed is a development program that is capable of addressing and rectifying the unsustainability of the present industrial development institutions, while also providing the foundations of a new (sustainable) development trajectory. In this sense, sustainability is as much like the climactic stage of a rainforest, having more to do with death and renewal than with birth and growth,[58] as it is about a journey, a vision of the future, or a 'road-map' for improvement.[59]

Conceptually then, sustainable industrial development must provide a robust framework to achieve these two separate but closely related goals. In this sense, it is suggested that industrial ecology in its manifestation as industrial symbiosis does not comprehensively address the deeply unsustainable nature of present industrial metabolism, and moreover, is yet to demonstrate a capacity to provide a foundation for a new sustainable industrial development trajectory.

The West Australian State Sustainability Strategy identifies sustainability as 'meeting the needs of current and future generations through *simultaneous* environmental, social, and economic improvement.'[60] In this context, it must be explored how, and if, industrial ecology as industrial symbiosis articulates a mechanism to move industry towards this shifting sustainability target.

The development of industrial resource interactions within a component of a greater system of industrial metabolism, such as the Kwinana industrial area, ostensibly represents a situation where industrial enterprise can be co-developed through co-location. In this sense, the mere documentation of industrial symbioses can be used as a powerful tool for identifying potential development opportunities in an existing industrial area. This approach is echoed by the 2002 economic impact study of the Kwinana industrial area that seeks to gain a comprehensive understanding of the resource interactions between Kwinana industries with the view to identify areas where potential developments have not been fully exploited. In this sense, the study of industrial symbiosis informs, posits, and addresses economic aspects of local resource maximisation issues.

The sustainability benefits of this in an economic sense are obvious - an industrial area will be more likely to continue to meet the needs of current and future generations if well defined industrial development opportunities can act as attractants for future development, thus ensuring ongoing growth. What is less clear is how ecological sustainability concerns, such as dematerialisation, detoxification, and

57 Yanarella, E. and Levine, R. 1992
58 Fricker, 2002, after Holling, C.S.
59 Trzyna, T. 1995
60 Government of Western Australia, 2002

decarbonisation are simultaneously addressed by this program of synergistic industrial development.

The notion that industries see benefit in their 'longevity within the Kwinana region' is significant from a sustainability perspective, as it demonstrates not only an imperative to sustain the ability of those industries to operate, but also an imperative for those industries to remain in the same place. This imperative of Kwinana industries to at least sustain their own operation, given that they are in a symbiotic network, must then extend to sustaining the operational viability of symbiotic partners in a fixed space over the longer term, indicating that the Kwinana industries involved in resource exchange are not on the whole 'fly by night' operations. Thus the value of maintaining 'longevity within the Kwinana region' provides a strong foundation to build broader sustainability principles into the operation and development of those industries, especially given their local symbiotic arrangements.

The following points can be considered together as possible sustainability outcomes of industrial symbioses as part of a broader eco-efficiency and cleaner production agenda.

- Improvement in the efficiency of resource utilisation (including transport resources)
- An increase in the profitability of industries as a result of cost savings;
- A decrease in the possibility of 'capital flight' as global industries are localised by dependencies on neighbouring industrial firms;
- A greater resilience to system shocks through a greater level of resource security;
- An increased capacity to understand local industrial resource flows and their impacts, through the creation of integrated resource exchange and tracking mechanisms;
- An increased level of communication, and therefore capacity building between industrial firms;
- An ability to easily recognise potential industrial development opportunities, ensuring continuing growth through attracting new enterprises to the area;

These outcomes taken together represent some net benefit in terms of sustainability as the State Sustainability Strategy defines the concept. However, even when combined with other eco-efficiency and cleaner production initiatives, it is unlikely that industrial symbiosis in the physical sense described above, will provide the foundation required to achieve the sustainability of industrial metabolism on a broader level as they are identified earlier in this paper.

Several flaws associated with the industrial ecology thinking that informs industrial symbiosis can be found. This is not to say that the ecological metaphor does not provide a useful model for sustainable industrial development, as the next section of this paper demonstrates. Rather, that in their enthusiasm for rational utilitarian ethics and engineering solutions, combined with an instrumentalist and mechanistic view of nature, industrial ecologists have often failed to ask important key questions of their discipline.

Contrary to the dominant industrial ecology viewpoint, the notion that the complex interconnection of components within a variable system promotes a fundamentally more sustainable model for system development, is informed by a lack of ecological understanding. Conversely, cursory examination of an elementary biology text reveals that food chains in ecological systems tend to be short and simple with few components, rather than long and complex with many components.[61] The reasons for these consistent characteristics of ecological systems are poorly understood:

> 'As yet, there is no clear consensus among ecologists about what causes food chains to be short, or about the best explanation for other common patterns in food webs. […] One set of models emphasises ecosystem stability: these models assume that the populations of organisms in a food web should return to stable equilibria after disturbance, and that populations able to return rapidly to equilibrium should be more likely to persist in variable environments. These models predict that systems with too many linkages, too many omnivores, or too many interactions between distant trophic levels are less likely to persist over time and through disturbances than are simpler systems.'

Figure 8 (below) illustrates common and uncommon properties of food chains as they operate in ecological systems. The diagram suggests that ecological systems exhibiting complexity and long food chains such as that displayed by industrial symbiosis, are uncommon in natural systems.

[61] Knox *et al* 1999

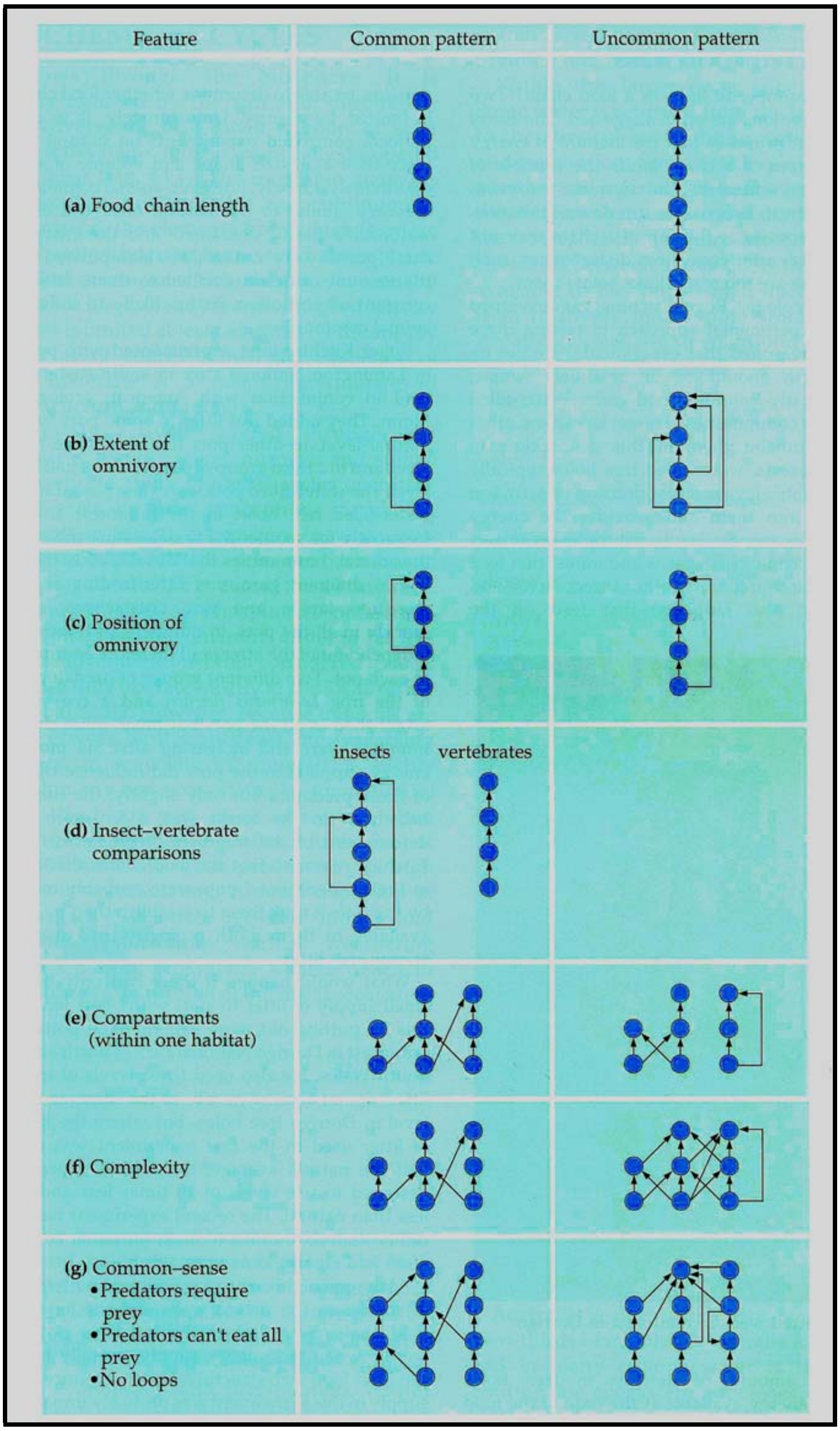

Figure 8: Modes of Common and Uncommon Patterns in Food Webs

Source: Knox *et al* (1999)

The industrial ecology assumption of sustainability being a function of symbiosis in systems also ignores the fact that a culture and infrastructure of connectivity between industries promotes lock-in development, or unsustainable path dependency. The Kalundborg example of industrial symbiosis, ironically, is an excellent example of this phenomenon. The system of resource exchange networks surrounding the Asnaes coal-fired power plant has maintained the operation of that industry in a country that has otherwise banned the burning of coal to produce electricity in response to environmental concerns associated with atmospheric sulphur and greenhouse emissions from coal-fired power plants. In this way, building the culture and infrastructure to connect industries creates a physical and cultural inertia to the fundamental change that will be required in some sectors of existing industrial development.

An ecological reading of the path dependency phenomenon is informed by the characteristic of adaptability in natural systems. In this way, a 'complex adaptive systems paradigm can be used to abridge theorising in ecological and economic sciences.'[62] Informed by the sustainability of natural systems in the sense that adaptability is a necessary condition for survival in variable environments, it can be seen that the efficiency of a system is negatively related to the adaptability of that system.[63] As the efficiency of a system increases, the adaptability of that system decreases. This can be illustrated just as well by the technology of the internal combustion engine as the dynamics of a natural ecosystem. To engineer and tune an engine to produce maximum efficiency, it must be perfectly tailored to the characteristics of its environment, from atmospheric pressure and composition, to operating speed and temperature. In this sense, an efficient engine is less flexible in, for instance, the types of fuel that can be used to power it; this engine has a very narrow octane range for the specific blend of fuel it can use, whereas a crude slow revving diesel can run on anything from fish oil to heated tar.

Returning to the ecological metaphor, an important, though relatively recent contribution to the science of ecology, Gaian science suggests that natural systems are both self-organising, and significantly, self-regulating.[64] Informed by the Gaian understanding of ecological systems as an interconnected living whole, symbiosis may not be the most significant factor determining sustainability, rather the ability of ecosystems to self-regulate, giving rise to the notion of *balance* in living systems. Self-regulation in natural systems, according to Gaian ecology, is an attribute arising from natural selection. It is this self-regulatory ability that functions on a global scale to limit, for instance, the overdevelopment of algal growth in a healthy estuarine system, investing nature with the perfect harmony between efficiency, and adaptability. On an eco-philosophical note then, the problem of industrial development does not reside in the realm of technology and efficiency, but in the question of required balance in living systems, the harmony between efficiency and adaptability.[65]

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[62] Matutinovic, 2001
[63] ibid.
[64] Kleidon, 2002, see also Camazine *et al* (2001)
[65] Matutinovic, 2001

The following possible outcomes of industrial symbioses, as an expression of, and combined with eco-efficiency and cleaner production, can therefore be considered inconsistent with the sustainable development of industry;

- Interdependence among industries reduces flexibility to change and promotes path-dependant development, therefore;
- Resource exchange networks may perpetuate unsustainable industries by developing industrial co-dependencies (coal-fired power plant in Kalundborg);
- Increased efficiency of economic system components can lead to greater consumption, and thus can be undermining to the sustainability of the system as a whole;
- Increasing efficiency reduces adaptability in complex systems;
- Complex interdependent systems with long ‘food chains’ are unstable in variable environments;
- Industrial symbiosis does not promote self-regulation; it may in fact be self-perpetuating to unsustainable forms of industrial development.
- A tendency to identify future development opportunities by resources maximisation economics, rather than the needs of the community;
- Efficiency-driven industrial growth does not lead to greater employment opportunities for the regional community (decreasing number of jobs while growth is demonstrated in the Kwinana industries);
- The identification of ‘wastes as products’ does not encourage a reduction in resource throughput (dematerialisation);
- Industrial symbiosis in its present articulation does not act to improve the failed relationship between industry and community stakeholders;
- Industrial symbiosis does not act to increase the level of community participation in industrial development and decision-making processes.

So, it can be concluded that the idea of industrial synergy as a delivery vehicle for industrial sustainability is lacking at best. Therefore, the attention of industrial ecology must be significantly broadened and redirected in the application of the ecological metaphor for the sustainable development of industrial systems.

Industrial Ecology – An Organic Organisational Perspective

'Our real future lies in building sustainable enterprises and an economic reality that connects industry, society, and the environment.'[66]

The human and institutional stakeholder synergies associated with industrial development arguably represent a more significant application of the ecological metaphor in its capacity to inform sustainable industrial development outcomes. The building and strengthening of these relationships potentially provides the foundations for a more radical shift towards sustainable trajectories for industry, however little work has been done in this area by industrial ecologists. A recognised land-use planning strategy for promoting sustainable industrial development is the integration of residential communities with industry.[67] It is the suggestion of this paper that a parallel process of community-industry integration must occur at the conceptual level of industrial development decision-making if sustainability is to be achieved.

Research conducted by the New South Wales Environmental Protection Authority confirms that Australian communities generally expect industry to be more responsible and less ecologically damaging. The NSW findings show that 60% of consumers and 80% of investors consider the environment.[68] Figure 9 (below) illustrates community perception with regards to the appropriate strength of environmental regulation by government. The high proportion of community members who perceive industrial environmental regulation as too lax supports the sustainability principle that community participation and representation in development decision-making will act to reduce the ecological impact of that development.

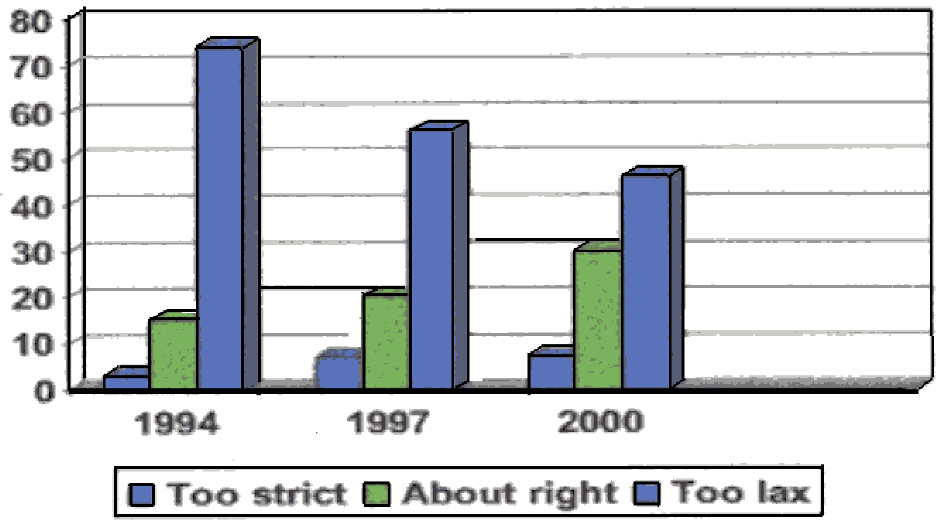

Figure 9: Regulations and Enforcement Supported by the Community

Source: Trewin, 2003

66 Senge and Carstedt, 2001
67 Shannon Smith 2002
68 Trewin, 2003

The remainder of this paper therefore advocates an evolution of industrial ecology thinking, expanding the field into applications that examine the societal and organisational interactions within business communities, as well as those interactions between business, community, and public sector industrial development stakeholders. This new and poorly developed breed of industrial ecology recognises that industry and society are inextricably linked, and emphasises fostering partnerships and networks to manage resources in more sustainable ways. Drawing from the ecological metaphor, this can be achieved by identifying and 'developing symbiotic networks among and between business, community, and the public sector.'[69] The key element here is not engineering solutions, but rather the social capital and creativity generated by people.

At this level of articulation, the industrial ecology analysis has significant resonance with regional sustainability planning as 'interconnections between businesses and the regions workforce, ecosystem, and institutional and community resources'[70] are considered. It is suggested that the social capital perspective of industrial ecology expands the notion of industrial synergy from a model of engineered resource exchange, to the ecological development of social and organisational synergies between community, industry, and public sector industrial development stakeholders. This perspective is briefly explored by examining those relationships as they are evolving in the Kwinana industrial region.

Before we delve further into the sustainability implications of applying an ecological metaphor to human metabolism and its associated organisational structures, it will be instructive to clarify why this may be a fruitful endeavour. A simple answer is that ecological systems demonstrate system sustainability; something that anthropogenic industrial metabolism has yet to achieve. Further, in order to move from a metabolic system which is in disharmony with its environmental support structures and therefore unsustainable, change is required of that system. The ecological metaphor provides a pertinent model with deep explanatory power for the analysis of structural change in metabolic systems, through insights gained from ecological understanding of evolutionary processes.

Industrial ecologists typically draw upon three (contestable) key governing qualities of natural systems to inform the sustainable development of industrial metabolism: renewable energy, recycling resources, and robustness.[71] According to classical ecological models the sustainability of natural systems is exemplified by these qualities, which imply an inexhaustible (solar) supply of energy to the system,[72] quasi closed-loop resource flows (permitting limited environmentally benign (diffuse, non toxic,) outputs), and ability to withstand system shocks through flexibility and redundancy.[i] Under this classical modelling of ecological processes, it is assumed that there is no self-organising element to systems, and that each individual system

[69] Schlarb, 2001
[70] ibid.
[71] Socolow et.al.1994; Metcalfe 1995, see also Marinova and Phillimore 2003.
[72] An interesting point to note here is that ecological systems have actually managed to invest a *surplus* of energy over time in the biogeochemical composition of the earths crust (fossil fuels).

component will naturally exploit any favourable conditions to its full competitive advantage, thus dismissing any notion of self-regulation.

This view of ecological systems is attractive in its application to industrial metabolism because it describes a model of ecological capitalism, however, several other deeper understandings of ecology are emerging which suggest very different characteristics of ecosystem functioning. There is good evidence to suggest, for example, that in mature ecosystems, cooperation is as important as competition,[73]while a Gaian perspective adds temporal scale to this rationale suggesting self-organisation for mutual benefit among ecosystems and their components over time. Deep ecology[74] and social ecology[75] add depth, suggesting mutualistic, non-hierarchical, and emancipatory principles for the organisation of social and infrastructural systems.

In order to understand through an ecological lens the more complex human and political interactions that connect industrial institutions to communities and the public sector, we must develop this more sophisticated and sometimes philosophical modelling of ecology. A deeper ecological metaphor must look beyond the balance sheet of physical resource transactions between components of ecological systems, and begin to examine the organisational and developmental dynamics of those systems. Varying spatial and temporal scales of ecological arrangements must be examined from the perspectives of sustainable systems functioning, organisational characteristics, and evolutionary development patterns to inform such an analysis.

While ecologists are at a loss to consistently and accurately describe the relationships that occur within natural systems from a complex organisational perspective, many threads of ecological understanding can be woven together in the application of an ecological metaphor to human systems, and organisational decision-making structures associated with industrial institutions. As in most cases, the actual functioning of complex systems in nature probably does not follow one model set of rules, but at different spatial and temporal scales displays characteristics of the various different models put forward by ecological analysis.

To illustrate the ecology of relationships between industrial development stakeholders, it will be necessary to examine a case study where these relationships are perceptible. The organisational ecology of development stakeholders in the Kwinana industrial region will be briefly examined for this purpose. Significant organisational and social capital is displayed among Kwinana industries, as witnessed by the complex resource exchange network identified earlier in this paper, as well as the collective action undertaken to address several local and regional issues, and the subsequent formation of the Kwinana Industries Council (KIC).

The building of social capital and stakeholder capacity in decision-making processes forms a fundamental of sustainable development at the local, regional and global level. The failing relationships between industry, community, and public sector industrial development stakeholders therefore represent a significant barrier to the achievement of sustainable industrial development in the Kwinana region. Sub-optimal outcomes for all stakeholders can be readily identified since the early

[73] Senge and Carstedt 2001
[74] Naess 1989
[75] Bookchin, 1980

development of the Kwinana industrial area resulting from the ongoing failure of these stakeholder relationships.[76] Some examples include:

- The closing of a toxic waste treatment facility at Brookdale in response to community concerns, despite no evidence to suggest there was a health or environmental problem at the site represents a sub-optimal outcome for industry;
- The decline in real employment (number of jobs) provided by the Kwinana industries during the last ten years,[77] reflected in rates of unemployment in the region at least twenty five percent higher than the national average,[78] represents a sub-optimal outcome for the Kwinana-Rockingham community;
- The high compliance costs and lack of consistency associated with industrial environmental regulation represents sub-optimal outcomes for industry and government.[79]

In a recent study into the poorly examined field of social capital as a determinant of industrial innovation, Landry *et al* conclude that 'social capital contributes more than any other explanatory variable to increase [both] the likelihood and radicalness of innovation in firms.'[80] In this context, Carayannis *et al* recognise 'communities of innovation' which can occur through the formation of strategic research and development (R&D) partnerships. 'The emergence of collaboration is facilitated by the sharing of knowledge across organisational boundaries, which promotes the formation of trusted relationships and builds social capital for further cooperation.'[81]

Environmental and safety concerns in the Kwinana industrial area have historically provided strong catalysts for collective action by industries, and have been important contributing factors to the formation of the Kwinana Industries Council (KIC).[82] Extensive sharing of laboratory expertise and equipment, library and information resources, and informal knowledge, as well as capital funding for consultancy etc. have occurred between Kwinana industries for several years, and these linkages seem to be strengthening and extending to the wider community.[83]

One step removed from the social capital between Kwinana industries, is the Western Australian Sustainable Industries Group (WASIG) hosted by the WA Centre for Excellence in Cleaner Production at Curtin University. This organisation actively facilitates information sharing and capacity building between 'a variety of government, industry, professional and community stakeholders' in pursuit of innovation for sustainability.[84] WASIG has developed a 'Statement of Cleaner Production,' for which it has 54 signatories[85] including many Kwinana industries, representing various industrial sustainability stakeholders and their commitment to the development of cleaner production.

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[76] Carman-Brown 1994
[77] Kwinana Industries Council *et al* 2002
[78] Dames and Moore 1996
[79] Martin Taylor, Kwinana Industries Council, Pers. Comm. 2003
[80] Landry *et al* 2002
[81] Carayannis *et al* 2000
[82] Martin Taylor, Kwinana Industries Council, Pers. Comm. 2003
[83] Ibid.
[84] WASIG 2003
[85] Van Berkel 2003

The intent of the cleaner production statement itself may not be as significant in a sustainability sense as the social capital created between signatory organisations. Multi-stakeholder collaboration to address sustainability issues of joint concern is promoted through the group, by, for example, NGO’s such as the Conservation Council of Western Australia working collaboratively with industries such as Westfarmers CSBP and government stakeholders such as the Department of Environmental Protection. The WASIG may therefore represent an important catalyst for the repair of failed industry–community relationships. Agreements such as the Statement of Cleaner Production also provide valuable tools for the support of demand-side management initiatives, as public and private sector consumers can access the information necessary to begin selective purchasing from, in this case, signatory industries.

An important factor in the building of communication networks and social capital between Kwinana industries has been the ongoing community criticism of industries that has resulted from a fractured relationship reflecting the inconsistencies between development agendas of industry, government, and community. This ongoing pressure has also contributed significantly to the formation and evolution of the Kwinana Industrial Council and its functional role of facilitating collective industry response to community concerns.

Regulation has also been an important factor in shaping the relationship between industries and the community in the Kwinana region. Recently, industries have increasingly acted in a proactive way, often through the KIC, to address issues that have been raised by the local community before cumbersome and expensive regulation is introduced to mandate remedial action. In this way, collective action by industries coordinated by the KIC has averted regulatory action concerning the abatement of noise pollution in the Kwinana area.[86] This situation represents willingness by industries to work with community to overcome issues in a way that avoids the sub-optimal outcomes of the past, and more generally, recognition that community concerns are important factors affecting industrial development.

The KIC has proactively developed a unique community-industries forum to facilitate an active and responsive dialogue between community, industries, and local and state government stakeholders. The bi-monthly forum is the largest and most comprehensive of its type in Australia,[87] allowing community members or groups to raise current issues with industry and government in a responsive forum aligned with the values of openness, honesty, goodwill, representative participation, caring, integration, and value-adding.[88] The community-industries forum was developed with the aid of the Kwinana Industries Council to address the problematic relationship and lack of trust between industry, community, and government sectors in the Kwinana industrial region. The forum may yet go beyond the conflict–resolution role it was originally designed for, and articulate a powerful mechanism to achieve integrated decision making and co-development between community, industry and public sector stakeholders.

[86] Martin Taylor, Kwinana Industries Council, Pers. Comm. 2003
[87] Kwinana Industries CIF Executive Group 2002
[88] ibid.

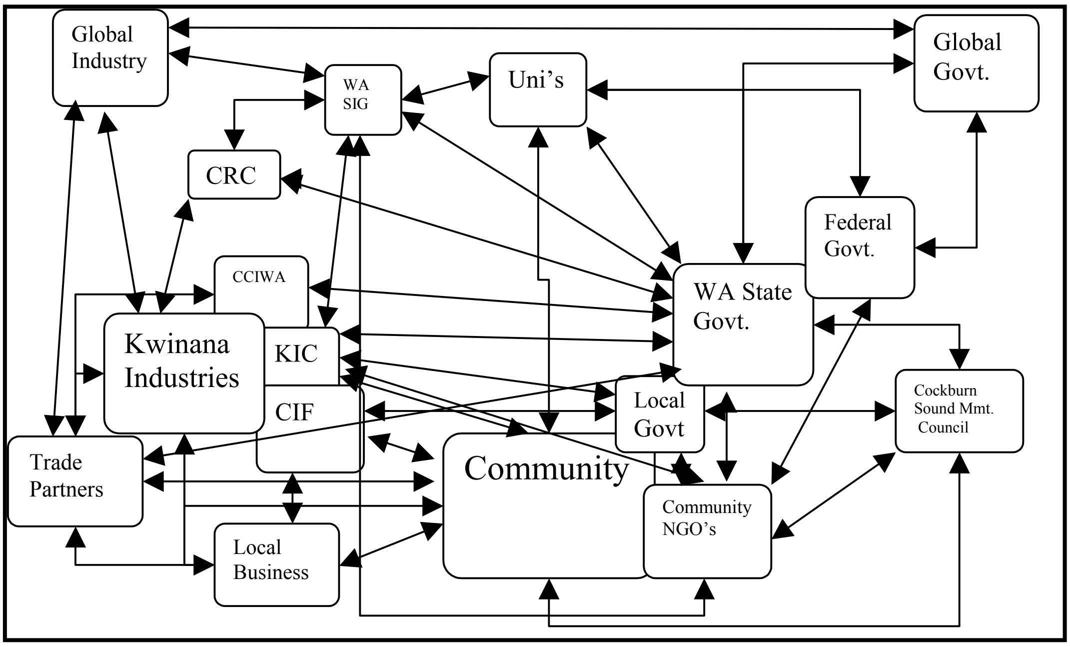

Figure 10: Example of Organisational Relationships between Industrial Development Stakeholders in Kwinana, Western Australia.

Key to Figure:

CCIWA – Chamber of Commerce and Industry of Western Australia
CRC – Cooperative Research Centre for Sustainable Resource Processing
CIF – Community - Industrys Forum
KIC – Kwinana Industry Council
Uni (s) – Australian Universities
WASIG – WA Sustainable Industry Group

Figure 10 (above) illustrates the organisational relationships between industrial development stakeholders in the Kwinana region. The diagram is not comprehensive in representation of all organisational relationships or all stakeholders, but provides an example of some of the organisational connections which are significant for sustainable development. As the diagram illustrates, the State Government of Western Australia, the Community in the Kwinana Region, and the Kwinana Industries associated organisations have complex organisational linkages representing information transfer and participation in development and decision-making processes. Significant social capital and capacity for sustainable development may be associated with these relationships if they are understood and fostered as an organisational ecology of regional development. The State Government of Western Australia has an important role in facilitating, and participating in the ecology of these relationships in order to integrate the vision of all stakeholders into a cooperative, responsive, and sustainable development strategy for the region.

Two organisational levels are significant in the sustainable development of industrial metabolism, reflecting the global, and regional spatial scales of industrial environmental impact. The globalisation of industrial development, as well as the global environmental issues associated with industrial metabolism requires that international stakeholders must strengthen relationships, and build capacity to address international sustainability agendas. Industry organisations at the international level are beginning to realise their essential role in working with non-government organisations, as well as the institutions of global governance in the abatement of international sustainability issues such as climate change.

From the perspective of the firm, transparency is becoming increasingly important in the preservation of corporate image, and the associated 'community licence to operate.' A powerful ally to sustainability, transparency may provide an imperative for the changes needed to implement more cooperative, mutualistic and representative (ecological) development models. 'Growing transparency has lead to the inclusion of voices traditionally outside the inner circle.'[89] Unlikely institutions such as Greenpeace and IKEA are forming partnerships that bridge the traditional disputes between environmentalism and the corporate sector to produce significant contributions to sustainability.[90] Through capacity building and the innovation that results from a joint approach to problem solving, industrial firms and industry organisations improve corporate image, and develop sustainability solutions by engaging in mutual agreements with governments and NGO's. These arrangements may take the form of sustainability covenants between industry organisations and governments that bind industry members to a code of practice while investing signatories with credibility and increased trust from shareholders, customers and campaigners alike.

The second organisational level that is significant in terms of sustainable industrial development is the regional level where community stakeholders are most directly affected by the environmental, economic, and social impacts of industry. At this level, more mutualistic development processes between industry, community, and the public sector also support sustainable development by meeting several important sustainability objectives, for example:

- Reducing ecological and social impact regionally where community is directly engaged in, and therefore can influence industrial decision-making;
- Optimising commercial and development outcomes for industry resulting from increased trust, capacity building, and generally repairing failed relationships with community stakeholders;
- Reducing the necessity for state intervention in the form of top-down regulation by building capacity for co-regulation, and fostering community and industry partnerships to support transparency, accountability, and self-regulatory approaches; and,
- Increasing both the likelihood and radicalness of innovation in the industrial firm.
- Decreasing capital flight by promoting place-based ownership and development of economic enterprise.[91]

[89] Senge and Carstedt 2001
[90] ibid.
[91] Imbrosico *et al* 2003

What is suggested here of course is a regional development approach that goes beyond the established rhetoric of community consultation, where instead, development is pursued according to a shared vision of the desired future for the region, informed by a strengthened sense of place as a binding agent. An ecological systems view to identify solutions to both economic development and environmental pollution problems can be supported by such a mutualistic interagency development platform. An evolving vision of development, reflecting all stakeholder requirements would provide sustainable industries with the security in the region that is much needed for ongoing commercial viability and safety of regional investment,[92]while empowering local communities with a sense of place and purpose.

Place-based ownership models of industry, such as consumer cooperatives and community and employee ownership can form robust local responses to the sustainability issues associated with globalisation.[93] These models of regional economic security are also supported by ecological modes of stakeholder representation in regional development decision-making. Through the same vision reflecting developer's needs as much as community concerns, empowered communities would be proactive in regaining viability and vitality through sustainable industrial development and employment opportunities, while regional environmental and health issues would be replaced with appropriate and profitable technology.

A growing acknowledgement by industry that businesses must get involved in their regional community and its and visions for the future may yet provide the foundation for a more sustainable form industrial development. Social capital and capacity building between industrial development stakeholders may catalyse a breakdown of the misconception that social, environmental, and economic goals are inevitably in conflict, but these new forms of decision-making will require and represent a significant departure from the industrial development paradigms of the past. Community involvement and consultation through institutions such as WASIG, the Kwinana Industries Council, and the Kwinana Community-Industries Forum can combine with the growing realisation of transparency and corporate social responsibility by industry in powerful ways. These capacity-building phenomenon provide fertile soil for the development of a richly diverse regional organisational ecosystem that is capable of articulating the fundamental imperative for sustainability through an integrated development vision.

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[92] Dr.Greg Power, Sustainable Technology Manager, Alcoa World Alumina, Pers Comm, 2003
[93] Imbrosico *et al* 2003

Conclusion

Significant benefits for society, indeed, a remarkable revolution of the human condition has been made possible by industrial development, however evidence shows that the industrial metabolism of the developed world is now threatening the sustainability of human prosperity. Australia's material and energy economy typifies the worst aspects of the unsustainable global resource metabolism, evidenced by the particularly high ecological footprint of the Australian economy, and the outstanding level of resource use per Australian citizen.

Ecological and social systems will no longer sustain the technological optimism of a simple heuristic approach to testing industrial development and technology for sustainability. Earth-system and ecological knowledge is underdeveloped, but when combined with economic modelling techniques and the interdisciplinary study of resource dynamics, recognition of the unsustainable industrial human condition cannot be ignored. Humans possess the capacity of understanding to combine these forms of knowledge into a new development agenda that cooperatively and systematically dismantles unsustainable path dependencies, while constructing the basis for a reflexive and representative ecological mode of prosperity.

In response these worsening environmental and social problems, industrial ecology has been forwarded as a development paradigm by which to redesign industrial systems for sustainability. Although the ecological metaphor offered by industrial ecology may prove to be a powerful tool for this purpose, the mechanistic and instrumental interpretation leading to a vision of industrial symbiosis supported by eco-efficiency and cleaner production is limited at best. Industrial ecologists have combined the technological optimism of production efficiency with a reductionist modelling of natural resource dynamics to produce a vision of industrial symbiosis that does not hold up under the scrutiny of sustainability.

Examination of industrial metabolism at the system level, informed by deeper analysis of ecological systems and the characteristics of neoclassical economics informs a very different conceptual framework for sustainability. It is clear that industrial efficiency initiatives themselves will not solve environmental health impacts and environmental justice issues as a result of industrialisation. Economic, political and social changes are also urgently required to dismantle the institutional path dependencies of unsustainability, and to steer industrial evolution toward a new trajectory of sustainable development.

This wider systems perspective must therefore inform policy opportunities for the development of a sustainable resource metabolism. Demand-side management techniques supported by a shift towards a service-oriented economy may provide pragmatic yet robust policy avenues for dematerialisation of Australia's resource metabolism. In line with key sustainable development principles, other policy instruments may be informed by an application of the expanded ecological metaphor to the promotion of desirable synergies, social capital, and capacity building between the community, industry, and public sector stakeholders of industrial development and decision-making.

It is suggested, therefore, that the ecological metaphor be directed towards the organisational development characteristics of industrial systems and their stakeholders at the regional and global levels. The organic development of community, industry, and government stakeholders with a shared sense of place in the Kwinana region, combined with a broader movement towards corporate transparency and social responsibility provides a strong foundation for sustainability. Where industrial development stakeholders can be linked by an integrated, representative, proactive, and evolving future vision of sustainability at both the global and regional levels, the resultant modes of development will begin to avoid sub-optimal, inequitable and unsustainable outcomes both by design and repair.

It is unclear how environmental, social, and resultant economic sustainability issues will shape the future of industrial development. What is certain is that these issues will prompt a redefinition of industrialisation as it has been known since the last industrial revolution. As government, community, and industrial agents of a systematically malignant but outwardly profitable industrial metabolism, we have a choice. The ostensible path - business as usual modified for efficiency and industrial symbioses is not particularly appealing, considering the likelihood of consequential ecological and social instability and the resultant unpredictable and irreversible change forced upon human development.

As an alternative to this unattractive scenario, industrial development stakeholders can respond to sustainability issues proactively, and more importantly engage recognised sustainability processes to promote profitable and sustainable industrial development outcomes. This will require immediately beginning a deliberate redesigning of the institutional and developmental relationships between industrial development stakeholders. Decision-making for sustainable industrial development must be based on a shared vision, arrived at through the sustainability principles of transparency, involvement, representation and cooperation between stakeholders. To build the capacity, the sense of place, and the social and organisational capital necessary to achieve industrial sustainability at a regional and global level, industrial decision-making and engineering must reflect the organisational ecology and self-regulating resource economics of natural affluence.

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Endnotes

[i] It should be noted that sustainability in this ecological sense does not imply the ultimate sustainability of individual ecosystem components; rather, long term sustainability of the entire system while the component structure may change over time. It is the ability of an ecosystem to change and adapt through rearrangement and restructuring of individual components, which promotes the robustness, adaptivity, and overall self-sustainability of the system. Other important characteristics contributing to the sustainability and robustness of natural systems art thought to include diversity, and a level of interconnectedness of system components allowing those components a degree of flexibility and individual agency. These principles are also considered by industrial ecologists to be informative and practical aspects of the ecological metaphor (Sachs et.al. 1998).

Adoption of the ecological metaphor is consistent with the goal of building economic sustainability to the extent that that goal is to develop and deliver economic systems that offer ongoing sustenance (rather than the related institutional and path-dependant pursuit of sustaining the economic systems which are developed). The ecological metaphor invests neoliberalist rational approaches to sustaining economic growth with a different rationality concerning economic sustainability. The metaphor suggests that for an economic system to be sustainable over the longer-term, and in a changing climate (political, social, ecological), the component structure of that system necessarily must change over time to adjust to those varying climatic conditions or selection pressures.

This implies that to achieve system sustainability (robustness) it is not the individual components of the system which should be sustained at the expense of the long-term sustainability of the entire system, rather, ironically, that the sustainability of the entire system **depends** on the **unsustainability** of individual components, or the ability of the system to restructure in response to changing political social and ecological selection pressures. This necessary restructuring of system components may translate into a punctuated equilibrium evolutionary development path of those components, i.e., a development process characterised by a periods of slow incremental change (temporary sustainability of system components), interspersed with large evolutionary jumps (or fundamental reconstitution and rearrangement of components) to reach different stable states. Further, the evolutionary change of system components as a requisite for system sustainability requires that some components may, if unable to undergo the level of change necessary to achieve a new stable state, simply cease to survive under new selection pressures (extinction).

This last point, and indeed the whole concept of punctuated evolutionary change within economic systems (and therefore, *of* systems), appears to be inconsistent with neoliberalist approaches to economic management, which inherently suggest that the sustainability of (steady) economic growth depends on the (indefinite) perpetuation of the system components that provide that growth. Moreover, neoliberalist management of economic systems for economic stability can act to stifle industrial innovation (Freeman and Soete, 1997) by (drawing from the ecological metaphor) sheltering the institutions of economic growth from selection pressures that would otherwise affect their sustainability and force a period of rapid structural change.

Path dependencies associated with unsustainable industrial institutions (economic system components) can therefore result from neoliberalist management for sustained steady ‘capital’ growth. The resulting situation is one where unsustainable institutions (of economic growth) are perpetuated in a steady state beyond the point where selection pressures would otherwise force structural change or extinction. The ecological metaphor suggests that this situation threatens the sustainability of the entire system, as the other operational components and eventually the entire system, by merit of its interconnected nature, becomes more deeply locked into the path dependencies of unsustainable development.