INDUSTRIAL ECOLOGY OPPORTUNITIES IN MELBOURNE: LITERATURE REVIEW

MILESTONE 2

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Prepared for the Smart Water Fund

by the

Institute for Sustainable Futures, University of Technology Sydney

in collaboration with partners from

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Centre for Design, RMIT University
University of Melbourne

Smart Water Fund

Our Water Our Future

This literature review has been prepared for the Smart Water Fund by the project team from the

- Institute for Sustainable Futures, University of Technology Sydney;
- Centre for Sustainable Resource Processing, Curtin University of Technology;
- Centre for Design, RMIT University;
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TABLE OF CONTENTS

1 INTRODUCTION

1.1 BACKGROUND AND SCOPE OF PROJECT

1.1.1 Preamble

The Smart Water Fund Industrial Ecology project aims to identify specific short to medium term opportunities for reduced impact of the wastewater from industrial systems in Melbourne through the cycling of resources between firms. The project will also identify strategic sectoral opportunities or leverage points in the industrial systems of Melbourne for further targeted research. Specific opportunities will be elaborated with the associated costs, timeframe and next steps required to realise these opportunities.

1.1.2 Smart Water Fund

The Smart Water Fund is an initiative of the Victorian water industry and the Victorian government to encourage and support innovative approaches to water conservation, recycling and biosolids management. The objectives of the Smart Water Fund are to:

- Reduce consumption of potable water
- Recycle water and / or biosolids
- Facilitate recycling of water and / or biosolids

1.1.3 Project components and deliverables

Industrial ecology seeks to reduce the impact of industrial systems by following the cyclical principles of resource use present in natural systems. This innovative project will be a first for Victoria by delivering a scoping study that systematically evaluates industrial ecology opportunities around water resources in Melbourne. The outcome will deliver a framework and tools to support decision making by water managers and industry that identifies industrial ecology opportunities and associated costs and their contribution to reducing the impact of the water cycle. These opportunities will consider water, energy and other priority materials (e.g. mercury, cadmium, TDS).

To achieve these outcomes the project consists of the following components:

- Literature and experience review to identify relevant local and overseas experience and readily available information in the Melbourne Region
- Consultation with experts in industrial ecology and water management, and with industrial stakeholders – directly and through workshops – for added input regarding priority areas (a focus on regions or resources streams), practical feasibility and significant opportunities
- Expert seminars linked to workshops that stimulate an industrial ecology learning culture; raising awareness of industrial ecology's potential and helping develop a shared vision
- Development of framework and tools for evaluating water input and output flows in the Melbourne metropolitan area to identify industrial ecology opportunities. The framework will address both qualitative and quantitative data made available by involved stakeholders

- An opportunity assessment matrix will map selected resource and water flows for key industry sectors in the Melbourne region and highlight priority areas for industrial ecology opportunities with regard to sustainable water use
- Preliminary assessments of priority sectors/areas will demonstrate the approach and assess indicative costs, infrastructure requirements and footprint reductions for industrial ecology opportunities within Melbourne plus consider strategies for wider implementation.

1.1.4 Definition of scope

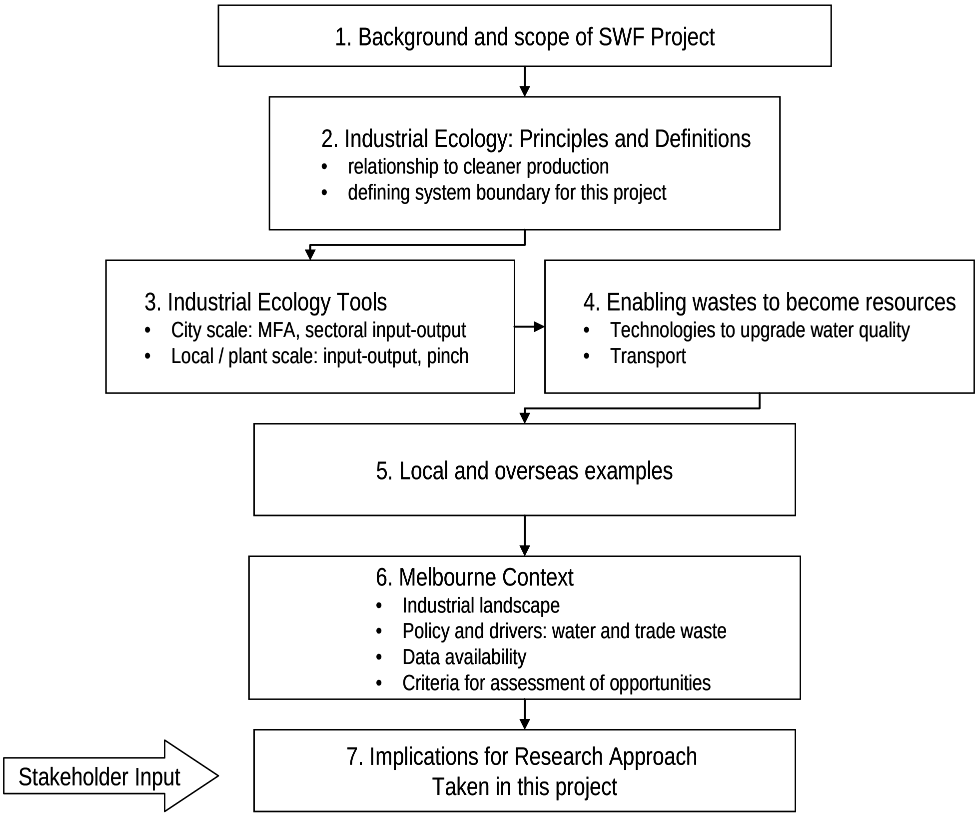
Due to the broad nature of conducting a 'scoping study' in a young field of inquiry, it is particularly important to define the boundaries of the research. In order to be considered as a possible industrial ecology opportunity that would be explored in this project, an opportunity must:

- be located within greater Melbourne;
- involve the recycling of water, the energy associated with heating water or contaminants within a wastewater stream;
- be able to be implemented within the next 5 years after the completion of the project (December 2007); and,
- demonstrate the recycling of resource that is considered by industry stakeholders to be a critical resource in the region of Melbourne.

1.2 OUTLINE OF LITERATURE REVIEW

The structure of the literature review is shown in Figure 1-1.

Figure 1-1: Structure of literature review



2 BACKGROUND TO INDUSTRIAL ECOLOGY

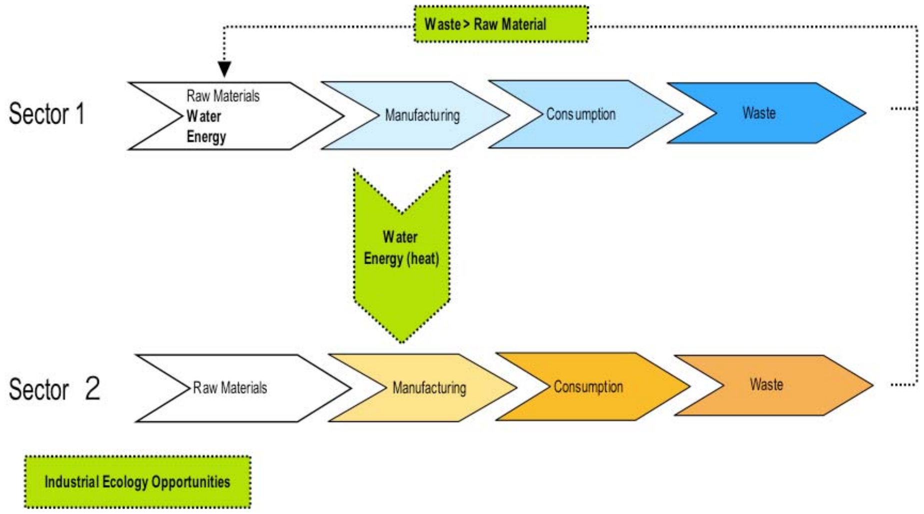
2.1 DEFINITIONS AND PRINCIPLES

Part metaphor, part analogy, the term 'Industrial Ecology' means different things to different people, and the process of defining it is hotly contested academic space. The increasing profile of industrial ecology is emerging in response to our resource-constrained world that demands new modes of operation for business. Establishing a standard definition and set of parameters for industrial ecology has largely proved elusive to date and some have viewed its pursuit as diverting from the task of achieving actual progress in the field.

There is however general agreement of the underlying principles and objectives of this emerging field. Industrial ecology seeks to reduce the impact of industrial systems by following the cyclical principles of resource use present in natural systems. Industrial ecology is 'industrial' in that it is concerned with product design and manufacturing processes, and views industry as an important source of environmental damage and its potential solutions. Industrial ecology is 'ecological' in that it looks to non-human 'natural sources as models for industrial activity (Frosch and Gallopoulos, 1989). Industrial ecology is 'ecological' in another sense, that it places human technological activity in the context of the larger ecosystems that support it, and examines the sources and sink of resources used by society (Lifset and Graedel, 2002).

Commonly, industrial ecology initiatives are concerned with reorganising supply chain processes at the firm or sectoral level to achieve environmental outcomes through recycling and dematerialisation. A conceptual schematic of recycling is shown below in Figure 2-1 where water and energy by-products from one particular sector become inputs into the process of another sector. This removes the need for Sector 2 to source these inputs from nature, and therefore reduced the abstraction of water resources and the resources needed to create energy. Another opportunity highlighted in this figure is the use of 'waste' by-products at the end of the supply chain as raw materials back into the process. Real life examples of this would be the reuse of metals from industrial wastewater, or the use of excess steam and heat from industrial processes to heat water.

Figure 2-1 Conceptual diagram of industrial ecology opportunities between two sectors



Lifset and Graedel (2002) outline six of the core elements of the field of Industrial Ecology:

- the biological analogy;
- the use of systems perspectives;
- the role of technological change;
- the role of companies;
- dematerialisation.

▶ The Biological Analogy and Metaphor

The use of 'ecology' is in some senses a metaphor, and in others an analogy, for what might be possible in the industrial arena. Ehrenfeld (2003) writes that understanding this distinction is critically important, and that " a central research objective of industrial ecology must be to establish the useful limits of this metaphor". The industrial ecology analogy, Ehrenfeld states, assumes that because things about industry and ecology are alike in some senses, they are also alike in others. An analogy is a map, useful to the extent that some rules about one situation may provide an alternative way of addressing a different analogous situation. For example, the recycling of biosolids in water treatment for use back in agriculture is analogous to the nutrients in nature. The ecology metaphor however does not assume that any rules are transferable between two situations, it is not a map. Rather, the ecology metaphor enables the practitioner to escape the rules that constrain routine action suggestively.

The extent to which the ecology analogy and metaphor are correct or useful is a subject of academic discussion, and there have been situations where these have proved problematic. For example, optimising the level of recycling in an industrial process could lead to a 'brittle system' scenario that lacks resilience to fluctuations in external factors. It may be possible therefore that adopting some ecological principles and not others, in this case recycling but not resilience, could prove problematic and unsustainable (Cohen-Rosentahl, 2004, see also discussion on limitations of concept by Korhonen, 2004)

▶ The use of systems perspectives

The field of Industrial Ecology employs systems perspectives in order to avoid narrow, partial analysis that can omit critical factors and system influences that may lead to undesirable consequences. Lifset and Graedel (2002) identify four main ways in which this systems perspective is incorporated into the field:

- use of a life cycle perspective, analysing environmental impacts from 'cradle to grave';
- use of materials and energy flow analysis through a reliance on mass balances;
- use of systems modelling that is comprehensive and captures the interactions that drive the behaviour of the system; and,
- sympathy for multidisciplinary and interdisciplinary research and analysis.

▶ Technological Change

Incorporating environmental considerations *ex-ante* is a recurring theme amongst industrial ecology research and practice. Many industrial ecology initiatives preference technological innovation over other forms of problem solving, however, the extent to which technological innovation can be useful in solving technological problems is an area of rich debate (Ausubel 1996).

▶ Role of companies

Businesses are central to the development and implementation of industrial ecology, most notably because business is the sector responsible for developing industry and therefore the sector charged with implementing ecological modifications to process. Business are also hold much of the knowledge, and much of the potential for developing future knowledge, about optimising environmental outcomes for industrial processes. Getting businesses on board to support industrial ecology initiatives in a collaborative manner with aligned goals is recognised as an effective approach to effective, environmentally conscious policy making in this area (Schmidheiny, 1992).

▶ Dematerialisation and Eco-efficiency

The central industrial ecology concept of closing the loop is complimented by a commitment to reduction of resource use while still achieving a standard level of service to society. Dematerialisation refers to the reduction in the quantity of materials used to accomplish a task, with the ultimate aim of decoupling resource use and environmental impact from economic growth.

- **Forward looking analysis**

The field of industrial ecology is orientated toward creating a particular future that involves achieving environmental goals through mechanisms such as dematerialisation and recycling. Much of the inquiry in the area of industrial ecology is centred around how to get to a certain more sustainable future scenario in terms of industry supply chains and configurations, and at what are the benefits and costs of reorganising the economy in this way.

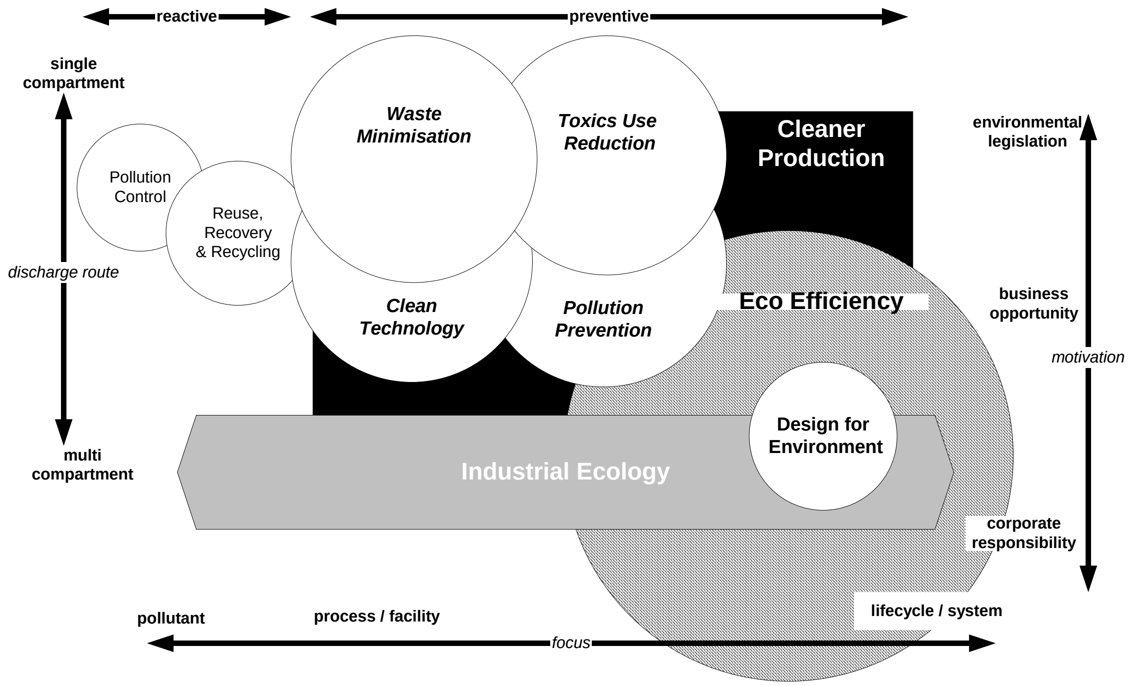
In conclusion, Industrial ecology is an emerging field that currently consists of a diverse collection of ideas, concepts, tools and case studies. There are many elements of the field that are highly contested territory, such as whether the field is purely descriptive or whether it has moral implications. However, underpinning all industrial ecology research and practice is a common concern for the impact of humans on the environment and the principles identified represent a sound basis to support the theoretical framework for this project.

2.2 RELATIONSHIP TO CLEANER PRODUCTION AND OTHER AREAS

Environmental management strategies and practices have expanded quite rapidly since the 1980s under a range of different terms, including eco-efficiency, cleaner production, pollution prevention and industrial ecology. Figure 2-2 positions these concepts in terms of focus and primary divers (van Berkel forthcoming). The figure shows that industrial ecology, cleaner production and eco-efficiency are truly complementary concepts. The older preventive approaches are waste minimisation, pollution prevention and toxics use reduction. Their use tends to be geographically bound and to a certain extent regulated. The newer preventative approaches explicitly target reduction of environmental impacts along the product’s lifecycle, by focusing on product design (design for the environment) or on approaches for value adding activities (eco-efficiency).

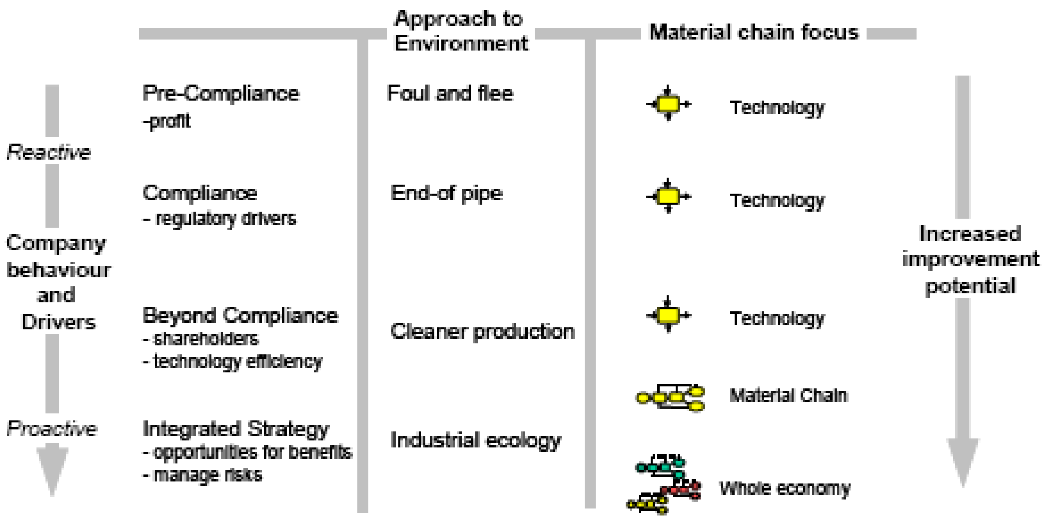
As shown in Figure 2-2, the concept of industrial ecology can be both reactive and preventive. For example, the exchange of wastewater between industrial operations is an end-of-pipe solution. In line with the waste management hierarchy, preventive measures should have preference above reactive measures. This means that eco-efficiency and cleaner production practices (as purely preventative approaches) need to be fully explored first before an assessment and development of waste(water) exchange opportunities (these exchanges are generally referred to as regional synergies, a subset of industrial ecology) in existing operations (contrasting new operations).

Figure 2-2: Industrial ecology in relation to other environmental management concepts (van Berkel forthcoming)



An allied conceptualisation of industrial ecology is illustrated in Figure 2-3, reflecting the plurality of interpretations regarding the concept. This figure does not see industrial ecology as reactive, but proposes that as the drive toward proactive company behaviours are pursued, an approach utilising industrial ecology is increasingly required, drawing on synergies between material chains, either at an eco-industrial park or city scale.

Figure 2-3: Industrial ecology in the context of company behaviours and drivers (Giurco, 2005 adapted from Willard 2005).



Company behaviour and Drivers		Approach to Environment	Material chain focus
Reactive	Pre-Compliance -profit	Foul and flee	Technology
	Compliance - regulatory drivers	End-of pipe	Technology
	Beyond Compliance - shareholders - technology efficiency	Cleaner production	Technology Material Chain
Proactive	Integrated Strategy - opportunities for benefits - manage risks	Industrial ecology	Whole economy

2.2.1 Industrial Ecology and Regional Synergies

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

Several other terms are used in the literature, including 'regional synergy', 'by-product exchange', 'eco-industrial park', 'eco-industrial network' or 'industrial ecosystem' (Bossilkov et al. 2005). Depending on the system boundaries, specifics of the project, its management umbrella, or even the geographical location, the above expressions may vary but generally they are used interchangeably. Regardless of the specific terminology in use, these initiatives have one thing in common: their implementation aims at "creating a system for trading material, energy, and water by-products among companies, usually within a park, neighbourhood, or region" (Lowe 2001).

In this research, the term 'regional synergies' is used to refer to exchanges of by-products, water, and energy between industrial operations. Overall, regional synergies can be divided into three principal categories (Van Berkel 2003; Bossilkov and Van Berkel 2004), i.e.:

- <u>Supply synergies:</u> featuring local manufacturer and dedicated supplier of principal reagents for core process industries (e.g. production of ammonia and chlorine for industrial use).
- <u>By-product synergies:</u> these involve the use of previously disposed by-product (as solid, liquid, or gas) from one facility by another facility to produce a valuable by-product.
- <u>Utility synergies:</u> these involve the shared use of utility infrastructure, and mainly evolve around water and energy (e.g. water recovery and cogeneration).

Supply synergies are not further addressed here in this study as such synergies are '*business as usual*', where a business realises a benefit from co-location with its main customers, a phenomenon well-known as agglomeration economy (Desrochers 2004). These supply synergies therefore do not meet the criterion of *'resource exchange between traditionally separate industries'* as the distinctive feature of industrial symbiosis (Chertow 2000).

The often-quoted icon example of regional synergy development at Kalundborg (Denmark) illustrates the sustainability and business benefits of regional synergies (Ehrenfeld 2003). From an Australian perspective, Kwinana (Western Australia) is a major heavy industrial region with a significant number of successfully operating regional synergies (Bossilkov et al. 2005; Van Beers et al. 2007). This Australian example of regional synergy development is discussed as a separate case-study in this literature review.

2.2.2 Cleaner Production and Eco-Efficiency

Cleaner production and eco-efficiency are guideposts for the business journey to sustainable development. Cleaner production is about preventing waste and emissions, including the loss of energy, rather than dealing with them once they have been generated. Eco-efficiency is about better products that have a lower ecological impact, are competitive and better meet customer needs.

Cleaner production deals with the efficient use of materials, energy, water and other natural resources when we conduct business, regardless of whether the business is in processing, manufacturing, service, transport, mining or agriculture. More precisely, it is generally defined as "the continuous application of an integrated preventive environmental strategy to processes, products, and services to increase eco-efficiency and reduce risks to humans and the environment" (UNEP 1999) (ANZECC 2000). Cleaner production aims at making more efficient use of natural resources (raw materials, energy and water) and reducing the generation of wastes and emissions at the source. This is generally achieved through combinations of five prevention practices: product modification, input substitution, technology modification, good housekeeping, and on-site recycling (USEPA 1992).

The World Business Council for Sustainable Development (WBSD) coined the term eco-efficiency for business to get involved in sustainable development. Eco-efficiency is "reached by the delivery of competitively priced goods and services that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life cycle, to a level at least in line with the earth's carrying capacity" (WBCSD 2000). The WBCSD identified seven components of eco-efficiency: reduce material intensity of goods and services, reduce energy intensity of goods and services, reduce toxic dispersion, enhance material recyclability, maximise sustainable use of renewable resources, extend product durability, and increase the service intensity of goods and services.

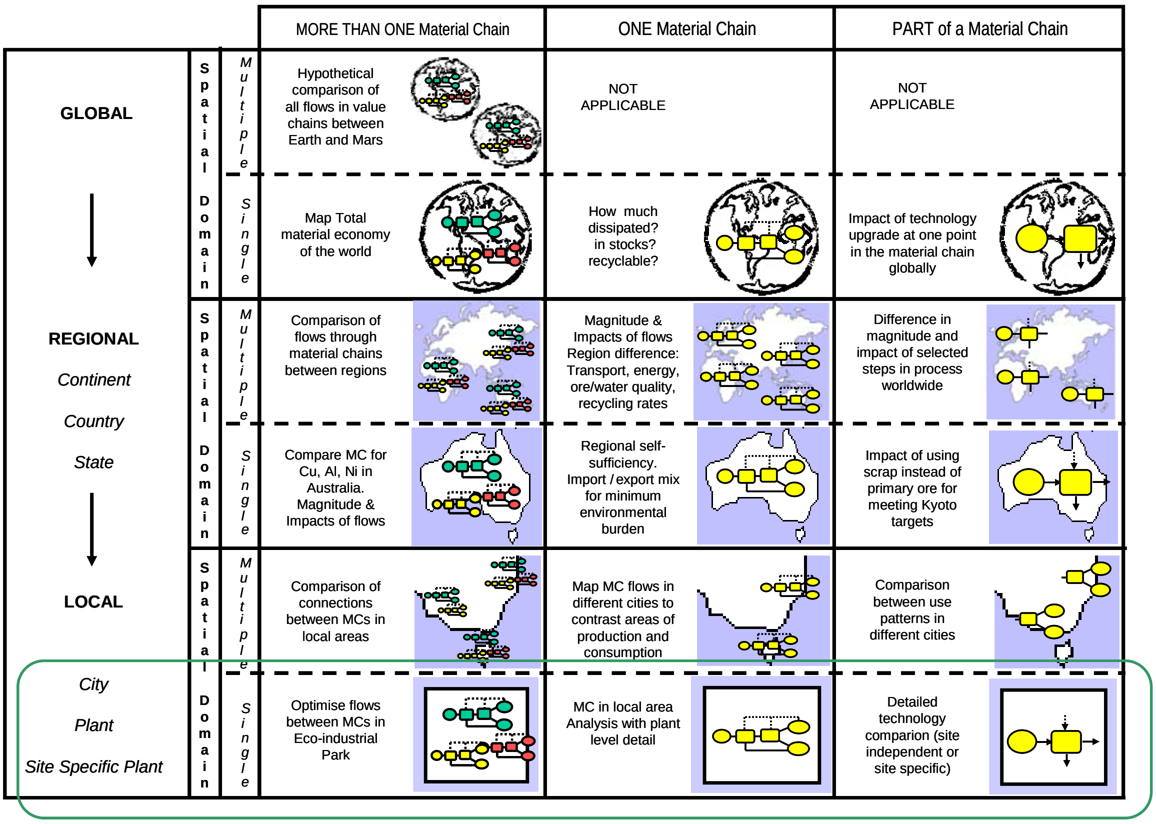
Implementation of the seven eco-efficiency components will most often call for practical changes that fall under either of the five generic prevention practices under the cleaner production umbrella (as above) and, vice versa, implementation of either of these five generic prevention practices will generally also achieve at least one, if not several, of the seven eco-efficiency components. Eco-efficiency and cleaner production are truly complementary concepts, with eco-efficiency focusing on the strategic side of business ("value creation") and cleaner production on the operational side of business ("production").

The many case-studies available in the public domain illustrate that cleaner production and eco-efficiency are valuable and constructive preventative approaches resulting in significant environmental and business benefits for the industries involved through optimisation and modification of their products, processes and services (Baas 1998; DEH 2001; van Berkel 2002; CECP 2004).

2.3 DEFINING OUR SYSTEM: INDUSTRIAL FOCUS

The question of scale at which opportunities can be pursued is depicted in Figure 2-4 for the case of analysing metal cycles (Giurco, 2005) however the conceptual approach to scales of analysis is equally applicable to considering industrial ecology opportunities for water. The specific focus for this project will be at the local scale, either considering synergies between more than one sector / material chain or within one sector or part thereof.

Figure 2-4: Reference schema for scale of analysis



			MORE THAN ONE Material Chain	ONE Material Chain	PART of a Material Chain
GLOBAL	Spatial Domain	*Multiple*	Hypothetical comparison of all flows in value chains between Earth and Mars	NOT APPLICABLE	NOT APPLICABLE
		Single	Map Total material economy of the world	How much dissipated? in stocks? recyclable?	Impact of technology upgrade at one point in the material chain globally
REGIONAL *Continent* *Country* *State*	Spatial Domain	*Multiple*	Comparison of flows through material chains between regions	Magnitude & Impacts of flows Region difference: Transport, energy, ore/water quality, recycling rates	Difference in magnitude and impact of selected steps in process worldwide
		Single	Compare MC for Cu, Al, Ni in Australia. Magnitude & Impacts of flows	Regional self-sufficiency. Import / export mix for minimum environmental burden	Impact of using scrap instead of primary ore for meeting Kyoto targets
LOCAL	Spatial Domain	*Multiple*	Comparison of connections between MCs in local areas	Map MC flows in different cities to contrast areas of production and consumption	Comparison between use patterns in different cities
City *Plant* *Site Specific Plant*		*Single*	Optimise flows between MCs in Eco-industrial Park	MC in local area Analysis with plant level detail	Detailed technology comparion (site independent or site specific)

Beyond consideration of the material and energy flows at each scale, there are prevailing actors (see at each scale who exert differing levels of influence over key variables. This is useful to identify up-front as the success of industrial ecology project depends both on identifying suitable changes to material and energy flows and associated infrastructure, and, on understanding the collaboration which will be required between different actors and which variables each actor has most influence over.

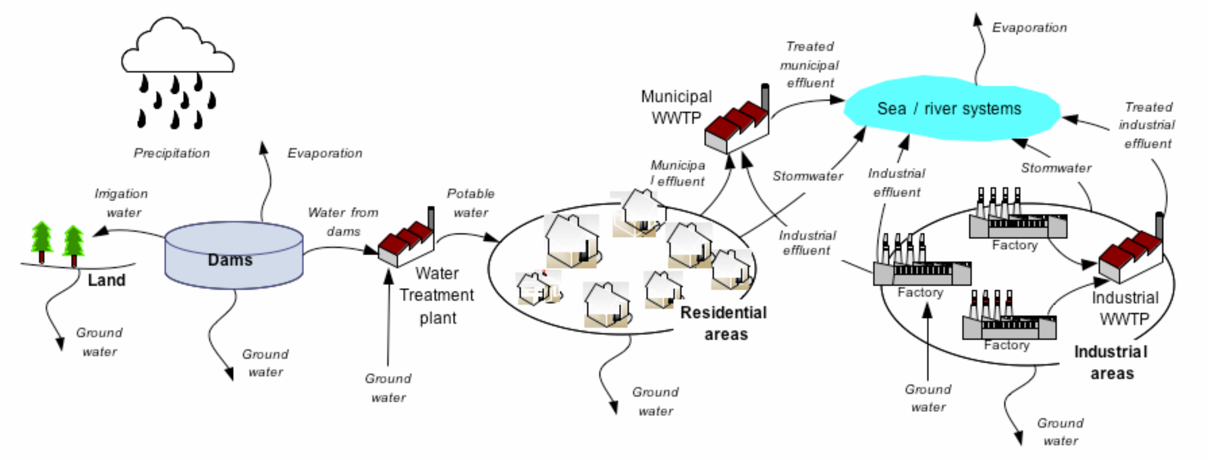
Figure 2-5: Actors at different scales (Giurco, 2005)

	MORE THAN ONE Material Chain	ONE Material Chain	PART of one Material Chain
GLOBAL	Multiple Actors • Governments • World Trade Organisation • Trading Blocs • Representative Companies • Representative Consumers	Multiple Actors • Governments • World Trade Organisation • Trading Blocs • Representative Companies • Representative Consumers	Single or Multiple Actors • Representative or Specific Companies (e.g. mining, refining, recycling) • Technology Vendors • Representative Suppliers
REGIONAL *Continent* *Country* *State*	Multiple Actors • National and/or Regional Governments • Regional Trading Blocs • Representative Companies • Representative Consumers	Multiple Actors • National and/or Regional Governments • Regional Trading Blocs • Representative Companies • Representative Consumers	Single or Multiple Actors • Representative or Specific Companies • Technology Vendors • Representative Suppliers
LOCAL *City* *Plant* *Site Specific Plant*	Multiple Actors • Government • Regulators • Industrial Parks • Specific Companies • Representative or Specific Consumers	Multiple Actors • State and Local Governments • Industrial Parks • Specific Companies • Representative or Specific Consumers	Single or Multiple Actors • Representative or Specific Companies • Technology Vendors • Representative or Specific Suppliers (energy, raw materials)

Figure 2-5 gives a generic list of actor types which play key roles at each scale. The term 'representative company' refers to a generic actor such as a water utility whilst the term 'specific company' refers to a specific organisation such as Melbourne Water. At the local scale which is highlighted of interest for this project, there are a diversity of actors involved which is the motivation for undertaking stakeholder workshops as part of this project.

With a specific focus on water, a schematic overview of a traditional (open-loop) water cycle is depicted in Figure 2-6. This figure is applicable to most urban societies, including the Melbourne Metropolitan Area. Various fresh water sources are used and discharged into the environment. Industrial effluent is either discharged directly to the environment, sent to an industrial waste water treatment plant or treated in a municipal waste water treatment plant. The realisation of water reuse opportunities can take place at different geographical levels, using various water resources for different domestic and industrial purposes. Due to the timeline and budget of the project, a selection needs to be made on focus areas of this study (e.g. which water resources, reuse applications). Such a selection exercise will be conducted at the stakeholder consultation workshop being organised as part of this study.

Figure 2-6: Schematic overview of a traditional (open-loop) water cycle in a urban society



Based on the figure above, the available water sources (in broad terms) within the Melbourne Metropolitan Area can be identified. These sources will provide the basis for the identification and evaluation of industrial ecology water opportunities. To assist decision making on the selection of water sources to include in this study, a preliminary assessment of the available water sources is presented in Table 2-1.

Table 2-1: Preliminary assessment of water sources available in the Melbourne Metropolitan Area

Water source	Alternative or desired water source?	Centralised or diffused flow?	Potential quantity	Possible focus area of this study?
Surface water	No	Centralised	Declining	No
Produced potable water	No	Centralised	High	No
Domestic and industrial stormwater	Possibly	Partly centralised	Declining	No
Groundwater	No	Diffused	Depleting	No
Household domestic effluent	Yes	Diffused	"Low" per household	No
Effluent from municipal wastewater treatment plants	Yes	Centralised	High	Yes
Aggregated industrial effluent from industrial regions	Yes	Centralised	High	Yes
Industrial effluent from individual companies	Yes	Depending on location company	High	Yes

The table above shows that three water sources are of interest for this scoping study.

An assessment on how these water sources could be reused is presented in Table 2-2.

Table 2-2: Preliminary assessment of water reuse options in the Melbourne Metropolitan Area

Water source	Potential use	Quality requirements / treatment costs	Potential issues	Possible focus area of this study?
Effluent from municipal wastewater treatment plants	Domestic	Medium	Required infrastructure (user side)	No
	Potable water	High	Community resistance (improving issue)	No
	Lower quality industrial water	Low to medium	What water price is industry willing to pay?	No
	Higher quality industrial water	Medium to high	What water price is industry willing to pay?	No
Aggregated industrial effluent from industrial regions	Domestic	Medium	Required infrastructure (user)	No
	Potable water	High	High community resistance	No
	Lower quality industrial water	Low to medium	What water price is industry willing to pay?	Yes
	Higher quality industrial water	Medium to high	What water price is industry willing to pay?	Yes
Industrial effluent from individual companies	Domestic	Company specific	Required infrastructure (provider + user)	No
	Potable water	Company specific	High community resistance	No
	Lower quality industrial water	Company specific	Water price, Feasibility depends on industry location and their specific water needs	Yes
	Higher quality industrial water	Company specific		Yes

Based on the preliminary assessments of water sources and their reuse applications, it is recommended to consider the following water reuse opportunities as part of this scoping study:

- Reuse of effluent from municipal water wastewater treatment plants as a low or high quality industry water (treated to the specific quality needs of involved industries)
- Reuse of industrial effluents (aggregated flow and from individual companies) as a low or high quality industrial water (treated to the specific quality needs of involved industries)
- Reuse of effluents from municipal water wastewater treatment plants and/or aggregated industrial effluents as domestic grey water (after treatment to sufficient quality standards)
- Reuse of effluents from municipal water wastewater treatment plants as potable drinking water (after treatment to high regulated water quality standards).

As outlined earlier in the literature review, preventative practices (such as eco-efficiency and cleaner production assessments) need to be explored before (or at least in parallel with) an assessment and development of above water reuse opportunities.

Reuse of biosolids from industrial effluent is also an important feature of this scoping study. Particular focus will be directed toward reducing the discharges to sewer and recycling of key contaminants that are a particular issue in the Melbourne region. At this stage the following list of have been identified:

- Cadmium;
- Mercury;
- Copper;
- Zinc;
- Total Dissolved Solids;
- Colour; and,
- Boron.

Reducing colour of industrial wastewater has also been identified as a barrier to domestic recycling.

Biosolids Source	Potential Use	Treatment Costs	Issues	Possible Focus
From municipal wastewater treatment plants	- Soil conditioning - Composting - Fertilizer - Energy generation - Alkaline Stabilisation	Company Specific - Potentiaily high	New infrastructure	Yes
Aggreagated industrial biosolids from industrial regions				
Industrial biosolids from individual companies				

3 TOOLS FOR ANALYSIS

3.1 CITY SCALE: MELBOURNE-WIDE

3.1.1 Bottomline3 (Environmental Impacts of Consumption, based on input-output tables)

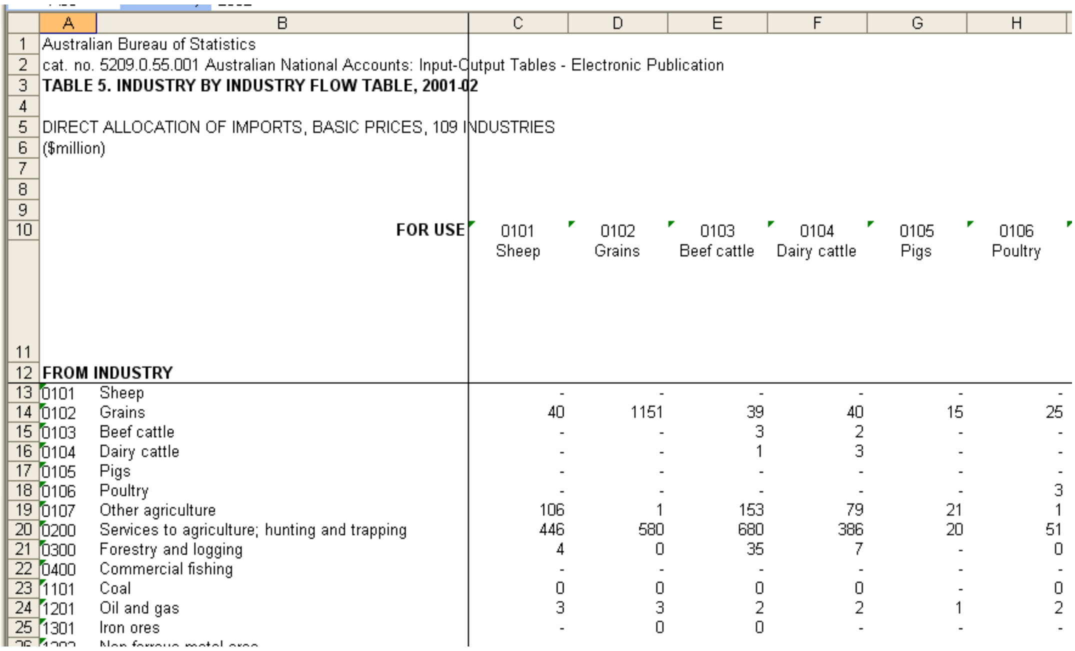
Research from the University of Sydney has underpinned the development of the software tool Bottomline3 (www.bottomline3.com). This tool uses economic input-output data, understanding linkages between the inputs and outputs of sectors in the Australian economy and overlays an assessment of environmental burden associated with these activities (see also (Foran et al. 2005; Munksgaard et al. 2005)). Companies can use the tool to estimate their environmental footprint based on the sectors in which they direct their expenditure. Inherent in this calculation is an estimate of average inputs and outputs from each sector of the Australian economy. This tool offers the possibility of being utilised to map high level possibilities for generalised synergies between sectors in Melbourne based on the Australian input-output data, however additional information is required about the proximity of potential synergy partners to consider in more detail.

An alternate approach can utilise the Simparo LCA software to give a similar output.

3.1.2 Simapro LCA Software

The input-output tables are tables of data listing the exchanges of money between different industry sectors in a given year. The latest tables are for 2001–02 (Australian Bureau of Statistics 2006) The tables can advise on the connections between different sectors, but once combined with greenhouse emission data from the Australian Greenhouse Gas Inventory (Department of the Environment and Heritage Australian Greenhouse Office 2006) and water data from the Water Account (Australian Bureau of Statistics 2000) the tables can provide information on water use and greenhouse gas emission for any sector of the economy, on a per dollars of expenditure basis. A sample of the supply and use table is shown in Figure 3-1 with the supply industries listed vertically on the left being used by the use sectors listed on the right. The 2001-02 tables breaks the economy up into 109 different sectors.

Figure 3-1: Sample of the supply and use table form the national input output tables.



Australian Bureau of Statistics
cat. no. 5209.0.55.001 Australian National Accounts: Input-Output Tables - Electronic Publication
TABLE 5. INDUSTRY BY INDUSTRY FLOW TABLE, 2001-02

DIRECT ALLOCATION OF IMPORTS, BASIC PRICES, 109 INDUSTRIES
($million)

FROM INDUSTRY	**FOR USE**	0101 Sheep	0102 Grains	0103 Beef cattle	0104 Dairy cattle	0105 Pigs	0106 Poultry
0101	Sheep	-	-	-	-	-	-
0102	Grains	40	1151	39	40	15	25
0103	Beef cattle	-	-	3	2	-	-
0104	Dairy cattle	-	-	1	3	-	-
0105	Pigs	-	-	-	-	-	-
0106	Poultry	-	-	-	-	-	3
0107	Other agriculture	106	1	153	79	21	1
0200	Services to agriculture; hunting and trapping	446	580	680	386	20	51
0300	Forestry and logging	4	0	35	7	-	0
0400	Commercial fishing	-	-	-	-	-	-
1101	Coal	0	0	0	0	-	0
1201	Oil and gas	3	3	2	2	1	2
1301	Iron ores	-	0	0	-	-	-

The resulting input output models have been implemented in life cycle assessment software such as SimaPro which provide graphical analysis of the sector flows and environmental impacts. Figure 3-2 shows a process network for 1 million dollars generated from the furniture sector with direct water use in kl in the lower part of each box and the flow between sectors in upper part of each box. Only sector with water contributions above 6% are show in diagram.

Figure 3-2 Process network showing direct water use into the forest products sector.

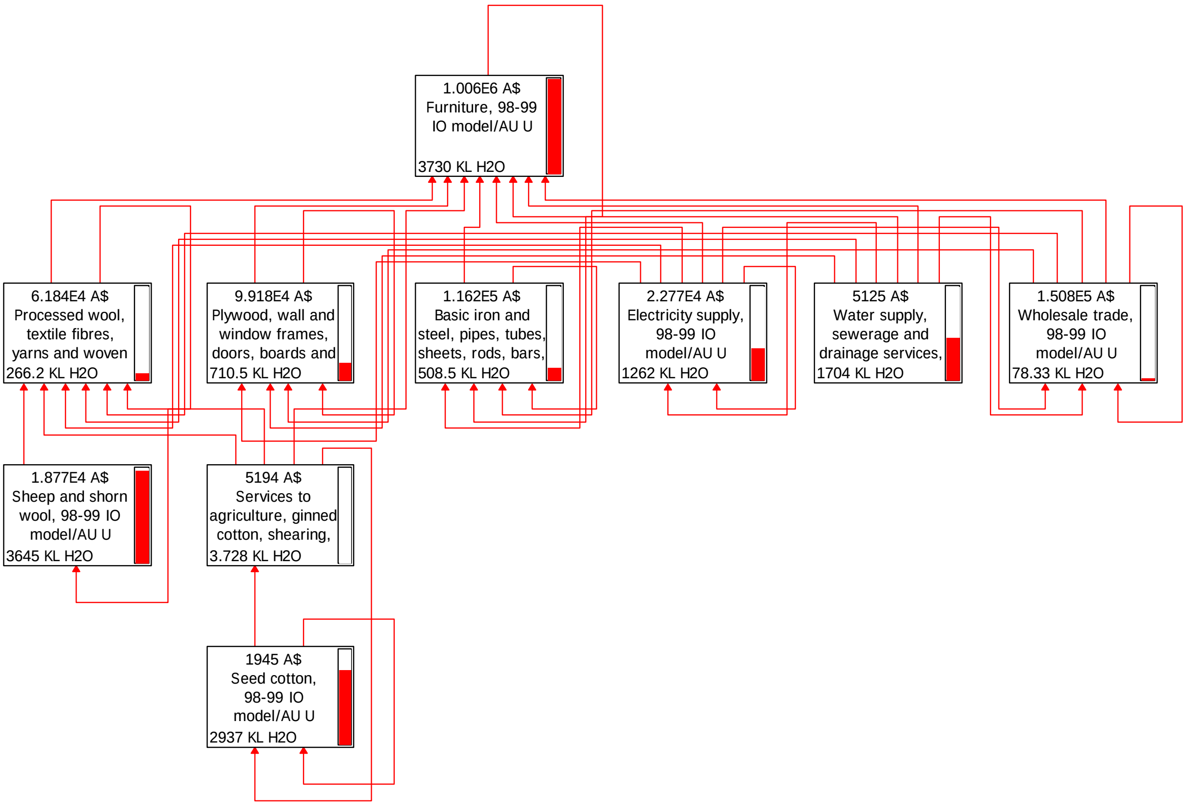
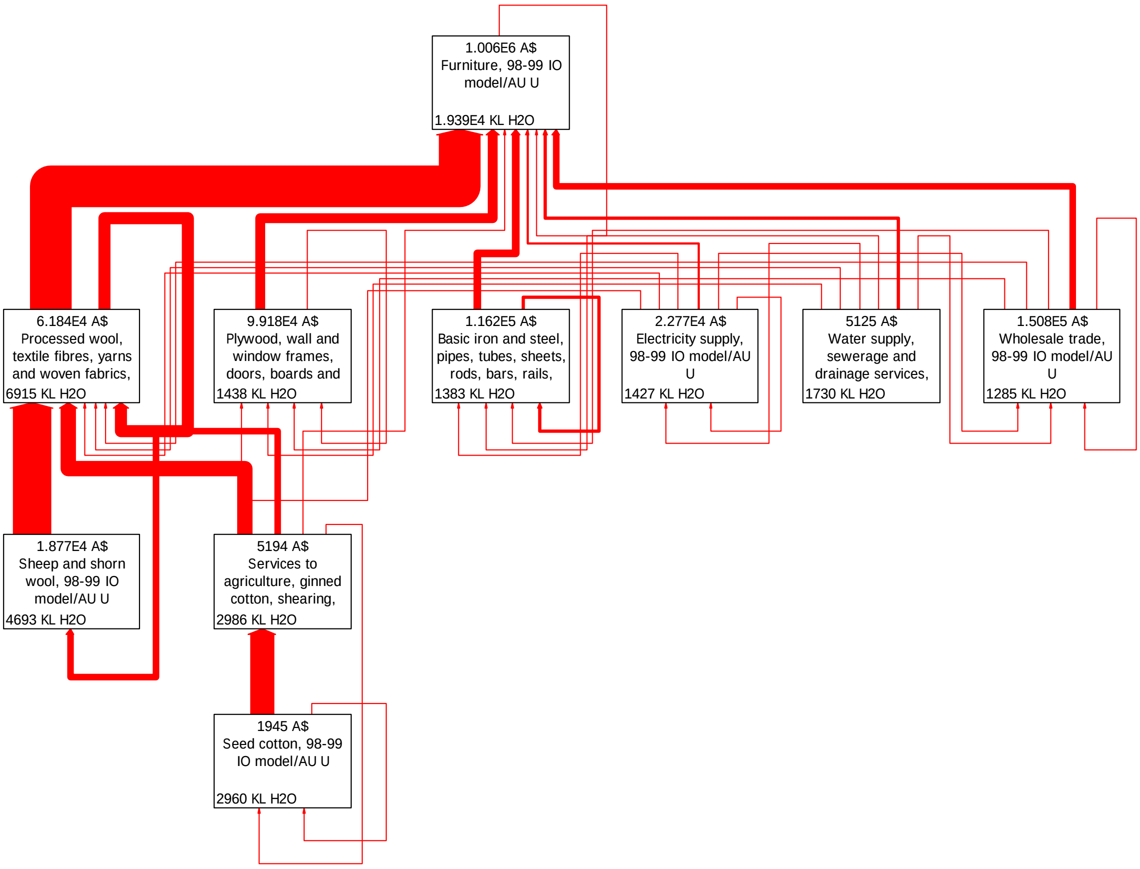


Figure 3-3 shows the same data with the cumulative water use across the supply chain of the furniture sector. This data can be used to determine direct and indirect water use, greenhouse emission or other environmental parameters for different economic sectors. This can be combined with specific company data in helping target key impacts areas.

Figure 3-3 Process network showing cumulative water use into the forest products sector.



3.1.3 MFA

Material Flux Analysis (MFA, also known as Material Flow Accounting) is a tool aimed at the management of materials and substances for resource efficiency (Wrisberg et al., 2002). Mass flows as an indicator of performance have been used to inform policy decisions in Australia (Daniels and Moore, 2002). This goal of MFA is supported on the premise that by understanding where materials are flowing through the economy, we are better placed to inform policy choices about how to manage the system. MFA in its classic sense studies the flows of several materials within a region while a MFA of a single material is termed Substance Flow Analysis (SFA). Notable SFA examples include the study of chlorine (Ayres, 1997), copper (Spatari et al., 2002) and cadmium and nitrogen (van der Voet, 1996). Many studies have a country or continent focus but could also be applied at a city scale to identify flows of particular materials, for example water and /or particular contaminants of interest such as cadmium and mercury. A detailed MFA for a specific component of interest would be difficult to find data for within the scope of this current project. Notwithstanding, the need for better water accounting in Australia in urban and rural areas has been recognised with $480 million being committed by the Federal Government to partly go toward "rigorous and nationally-consistent water usage measurement and accounting" (Howard, 2007).

3.2 LOCAL AREA AND PLANT SCALE

3.2.1 Material Input-Output

3.2.1.1 Waste Exchange Websites

Local, regional, national and even international waste exchanges traditionally represent a secondary materials market place. Variety of industrial operations, businesses, offices, schools, and individuals "advertise" their waste streams, surplus/unwanted materials, or materials they are seeking, by submitting an electronic request to the owner of the web based waste exchange. The listing is then posted on the respective web site, which is updated on regular intervals. This type of service is widely spread in UK, USA and Canada, as well as in other countries but not to the same extent. A few examples include the Business Reuse Network (http://www.mnexchange.org), Waste Exchange UK (http://www.wasteexchangeuk.com), and Industrial Materials Exchange (http://www.govlink.org/hazwaste/business/imex/index.html) and in Victoria the Waste Exchange database http://www.wasteexchange.net.au/index.asp).

The waste exchange websites generally try to "match-up" generators of waste with companies or individuals interested in recycling or reusing these materials and their effectiveness is largely dependant on the supply and demand posted.

3.2.1.2 Industrial Materials Exchange (IME) Tool

Very few tools of this type are known globally, with very limited application and reported benefits. The most widely cited tool for Industrial Ecology design and is intended for use in the identification and analysis of by-product synergies, as well as for planning new eco-industrial projects is the *Industrial Materials Exchange (IME) Tool*. It is a proprietary tool developed by Bechtel Corporation (now Nexus), not available to users outside Bechtel. Originally developed as a database of material flows associated with selected industrial processes, the tool can be used to design new eco-industrial parks, as well as to identify new synergetic interactions between existing industrial facilities. It has been used in Brownsville, Texas region (BCSD-GM 1997) and in the demonstration project in Tampico, Gulf of Mexico (Young 1999).

Further collaboration between Bechtel and the US DoE's Idaho National Environmental Engineering Laboratory (INEEL), has resulted in a "next generation" version of IME, known as *Dynamic Industrial Materials Exchange (DIME)*, that incorporates dynamic simulation of material flows to aid the design and analysis of by-product synergies that are affected by fluctuation in material availability or process requirements (INEEL (n.d.)).

For the current project in Melbourne, the focus is less on planning new eco-industrial developments and more on identifying synergies from existing industries.

3.2.1.3 Facility Synergy Tools (FaST)

A similar tool development was initiated by USEPA in 1997 to help users to identify, screen and optimise by-product utilisation opportunities at a regional scale. The toolkit consists of three interrelated components:

(1) *Facility Synergy Tool (FaST)*, is a database application that helps a user to identify potential matches between non-product outputs (NPO's) and the resource requirements (material and energy) of common industrial processes. It allows the user to quickly identify potential by-product synergies between facilities, or identify the types of industrial partners that can be recruited to serve as "sinks" for waste streams from existing facilities. The database has a major limitation, since it contains rather low number (35) of pre-determined input/output facility profiles;
(2) *Designing Industrial Ecosystems Tool (DIET)* uses the by-product synergy matches identified in the FaST database tool as inputs to a linear programming model, which generates optimum scenarios for industrial synergies; and
(3) *RealityCheck*™ is a screening tool that identifies potential regulatory, economic and logistical constraints (barriers) to by-product utilisation opportunities.

These three tools have been applied in the design and planning of the Eco-Industrial Park (EIP) in Burlington, Vermont (Industrial Economics 1998). FaST was used to identify potential linkages, while DIET has helped the planers and decision makers to investigate the estimated benefits of different EIP scenarios and the RealityCheck was applied to recognise potential constraints on potential exchanges.

The FaST tool is currently available to download, use and/or evaluate from http://www.smartgrowth.org/library/article.asp?resource=431. The DIET tool was a prototype that is no longer available (Giannini-Spohn 2004) and the status of the RealityCheck is unknown.

3.2.1.4 Industrial Ecology Planning Tool

An approach with direct relevance to this project is the *Industrial Ecology Planning Tool* developed by Carolyn Nobel (Nobel 1998). The tool incorporates a Geographic Information System (GIS) to help identify feasible water reuse networks and to allow transportation costs to be explicitly included in the optimisation of these networks. By matching streams with compatible water quality criteria, the model identifies feasible water reuse opportunities within the region of interest. Since any individual wastewater stream may have several potential uses, the feasible matches are passed to a linear programming module to calculate the optimal water reuse scenario.

This tool was used to identify and optimise water use and reuse opportunities within a complex of approximately 20 different industrial facilities at the Baytown Industrial Complex in Pasadena, Texas. In this relatively simple example, economically feasible water-reuse networks were identified that had the potential to reduce total freshwater use by more than 90%, while simultaneously reducing water costs by 20%.

The tool was developed using commercial "off the shelf" GIS software and a widely available mathematical optimisation package. Although the tool was developed specifically to illustrate the optimisation of industrial water reuse networks, the underlying approach can be extended to other industrial materials with relatively little additional effort.

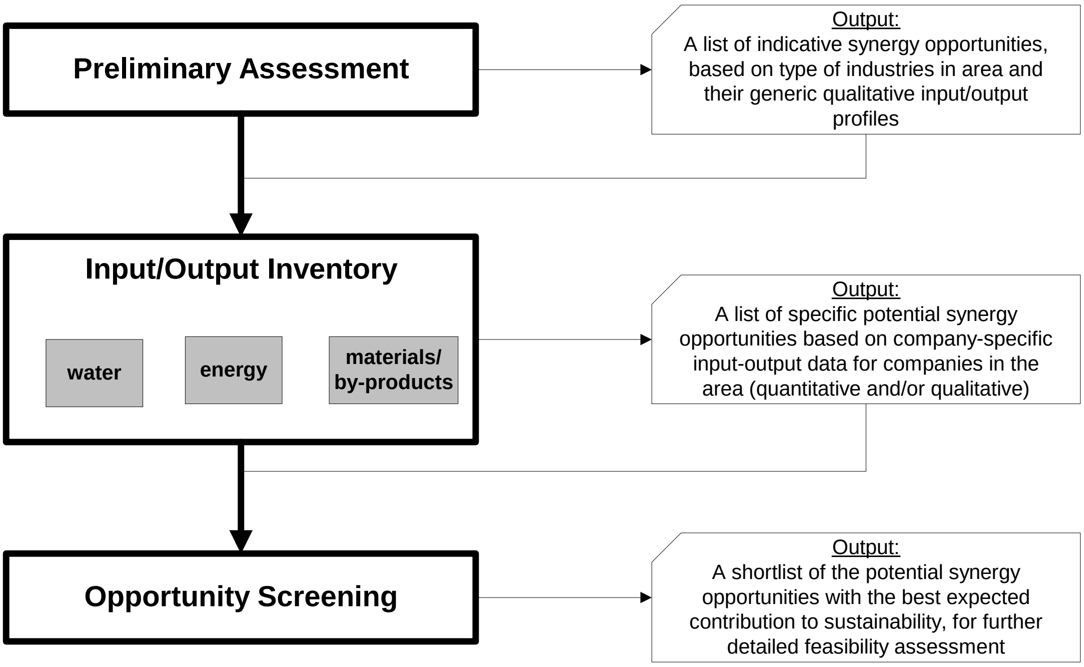
3.2.1.5 Regional Eco-Efficiency Opportunity Assessment Toolkit

In order to systematically identify and facilitate the identification and development of synergy opportunities a *Regional Eco-Efficiency Opportunity Assessment Methodology* is currently being developed at Curtin University of Technology with the support of the Cooperative Centre for Sustainable resource Processing (CSRP) (Bossilkov and van Berkel

2005). In its final version it will represent a step-by-step routine with instructions on “how to” at each stage, comprising a number of enabling tools, such as datasheets, various templates and most importantly a set of application tools that facilitate and aid organisations in their decision making process. The methodology is currently targeted for use by facilitator/s of regional synergy developments. However it may also be useful for companies looking for an outlet for one or more of their outputs or looking for an alternative input/s.

The opportunity assessment methodology is currently divided in three stages, which each stage using a set of inter-related application tools and accessing information resources. The stages are: preliminary assessment, inventory and screening (Bossilkov and van Berkel 2005). Whereas the preliminary assessment requires limited data to appreciate the potential scope for regional resource synergies in a given industry area, subsequent stages require more detailed information to target on these synergy opportunities that are most likely to be practical and beneficial (see Figure 3-4).

Figure 3-4: Overview of the regional synergy opportunity assessment methodology (source: Bossilkov and van Berkel (2005)



A list of indicative synergy opportunities, based on type of industries in area and their generic qualitative input/output profiles

A list of specific potential synergy opportunities based on company-specific input-output data for companies in the area (quantitative and/or qualitative)

A shortlist of the potential synergy opportunities with the best expected contribution to sustainability, for further detailed feasibility assessment

The *Preliminary Assessment Tool* aims to provide an overview of potential synergy opportunities within an industrial area and establish the business case for further data collection and identification of prospective synergy projects (Bossilkov and van Berkel 2005). The tool has in-built qualitative information regarding major input and output flows for more than 100 industries with an option of adding new industries in or updating the input-output flows, at the discretion of the user. The tool can potentially provide assistance at the later stages of the synergy identification process to specifically target companies that have greater potential to be involved in synergy projects. The output of the Preliminary Assessment Tool is an extensive list of indicative synergy opportunities based on the pre-loaded input/output flow data for each respective industry.

The three *Inventory Tools* (Input/Output Inventory stage) aim to generate registers of more specific synergy opportunities in three main groups: water, energy and materials/by-products. All three are designed in a similar manner requiring company-specific information, distances between companies and specific quality and quantity parameters. A search function is provided to allow identification of potential matches as per the user's specification and generate different output reports (Bossilkov and van Berkel 2005).

- The *Water Tool* is structured to assist the user in building up an inventory of effluent and influent water streams of each major water user in the given region. Data on the type of the water stream, quantity, frequency of discharge and an array of quality parameters (e.g. Total Suspended Solids, Chemical Oxygen Demand, pH, etc.) are required. In the search section the user can search an influent or effluent water stream that satisfies a single specific parameter, or number of parameters, or alternatively, generate a list of all available water streams in the industrial area ranked as a function of quantity and distance. The water tool thus generates a register of the most likely water synergy opportunities (in terms of volume, quality and distance). Each of these will then be subjected to a further analysis, considering treatment options and other engineering and business considerations.
- The *Energy Tool* is structured to assist users to generate a process energy inventory (waste heat streams and process energy requirements, in particular those most amendable to using lower grade waste heat, e.g. cooling, refrigeration, space heating, process pre-heating, drying, moisture removal, etc). The energy tool generates a list of the process heat sources and potential sinks in the industrial area, optionally rated on the energy content/requirement, temperature and distance.
- The *Materials/By-Products Tool* collates data for all solid, liquid and gaseous inputs and outputs, excluding water, fuels and power. The materials and by-products are classified in categories and subcategories (e.g. category: Acids and acid solutions, subcategory: sulphuric acid). The pre-established categorisation increases the probability of successful matching by eliminating the possibility that similar flows are named differently, misspelling by user, etc. The tool provides searching and matching sections returning registers of available flows satisfying the search criteria. It can also generate listings of potential uses of by-products/sources of alternative materials other than the input/output matches. It can also look for "economies of scale", whereby similar materials/by-products from several companies are combined into a single stream.

The *Screening Tool* assesses the potential contribution to sustainable development for the potential synergy opportunities identified at the previous stage (Bossilkov and van Berkel 2005). The tool is designed to provide direction in the search for the most beneficial synergy opportunities, in terms of their contribution to sustainable development (based on IISD (2002)) as well as their expected feasibility and ease of implementation (technical difficulty, project costs, regulatory approvals and community acceptance). The screening tool generates a report with priority synergy opportunities for detailed techno-economic evaluation.

The core structure of each application tool has been defined, and developed in Microsoft™ Access. Current efforts focus on piloting them for the development and selection of regional synergy opportunities in the case study regions (currently Kwinana and Gladstone). The prototype of the developed methodology was trialled in Kwinana and Gladstone, feeding largely from data collected as part of the CSRP Kwinana and Gladstone Synergies Projects

(Bossilkov 2006). The Preliminary Assessment Tool has so far been applied to two industrial regions in Australia, Geelong (Victoria) and Wagga Wagga (New South Wales).

3.2.2 Pinch analysis

More efficient integration of process streams can be undertaken both for heat integration (e.g. see (Linhoff March 1988) and mass integration (water) for contaminant rich and lean streams (e.g. see Wang and Smith, 1994). These options are most commonly undertaken within plant boundaries, but could also be applied between companies in an industrial park. The analysis can be undertaken based on water quantity or stream mapping (which is not technically a water pinch analysis). The use of multi-objective pinch analysis considering both water and energy has been successfully demonstrated by (Treitz. 2006) with case studies in Chile and China.

3.2.2.1 Water PINCH

A computer-based tool of interest for undertaking pinch analysis is *Water PINCH* – for any water-related process it is possible to construct a composite profile of water demands (sinks) and wastewater effluents (sources). Water pinch analysis is a systematic approach, using computer-modelling techniques, to optimise water reuse and recycling in complex manufacturing operations. The objective of water pinch analysis is to reduce the overall demand by quantifying potential water savings and identifying how these savings can be achieved. Water pinch has been applied in an industrial ecosystem project in the Rotterdam, The Netherlands, where it showed the possibility to develop an optimal water use and cascade circulation both within companies as well as in clusters of companies (Baas 1998).

3.2.3 Modelling considerations in urban water

3.2.3.1 Spatial scale

Most urban water models cover a subsystem within the whole urban water cycle although downfalls associated with engineering a set of disintegrated subsystems have been known for years (Stewardson et al. 1995).

There is great variety in the spatial scale represented in models. Examples range from the small-scale DYRESM, (Antenucci et al. 2003), which models one-dimensional hydrodynamics in a water column, to UVQ (Warhurst and Mitchell 2000), which covers the whole urban system . A small handful of models cover the whole urban system, and these are reviewed in Section 3.2.6.

It is common for several small-scale models to be linked to form a larger integrated modelling system. Several integrated subsystem models exist for urban watersheds (Rousseau et al. 2005). An example is the US EPA's BASINS, which models runoff and stream quality by linking HSPF, QUAL2E and TOXIROUTE (Whittemore and Beebe 2000). Problems with diversity in time scale and data type, and poor model accuracy are common when linking several subsystem models (Schmitt and Huber 2005), and research is now focussing on developing better 'integration modules' to improve linkages (eg. Maheepala et al. 2005).

The spatial layout of most sub-system urban water models is represented using linear flow networks in a single plane of scale (for example Cresswell et al. 2002; McAlister et al. 2004). This is sufficient for a subsystem model, however in the larger system, the spatial complexity of the networks becomes difficult to represent in a single plane (Hardy and Graedel 2002). A multi-layered, hierarchical network offers an elegant alternative. The hierarchical network structure is used a few urban water models, such as UrbanCycle (Hardy and Graedel 2002) and URWARE (Jeppsson et al. 2005).

3.2.4 Dynamic vs. Steady-state modelling

Models can be based on dynamic or steady-state material and energy balances. Most urban water models are dynamic, however steady-state models for subsystems exist, such as runoff/stream quality model QUAL2E (US EPA 1995). Using steady-state balances in urban water models is not appropriate, given that household demand varies by one to two orders of magnitude during each day, and simulating dynamic response to peak demands is essential to assess system stability.

3.2.5 Temporal scale

The dynamic processes in urban water systems are described by differential equations, which define changes in variables such as flowrate and concentration with time. Most dynamic urban water models simplify these differential equations by converting the continuous differential term (dx/dt) into a discrete fraction ($\Delta x/\Delta t$) (Nix 1994). The resulting algebraic equations are simpler, and readily solved by digital computers (Nix 1994). The magnitude of the time step chosen, Δt, presents a limitation to the applicability of the model. A shorter time step means increased accuracy and ability to simulate fast processes, however it increases input data requirements, simulation time and computer processing power required. Some models, such as SWMM (Rossman 2004) and SEWSYS (Ahlman and Svensson 2005) allow the user to define the time step.

3.2.6 Material & Energy Flows in Dynamic Water Models

Many urban water models simulate the total volumetric flowrate of the process stream only (eg. Bathurst and O'Connell 1992; eg. Warhurst and Mitchell 2000; Hardy and Graedel 2002), although some have been subsequently modified to include contaminant transport. Total flowrate data is sufficient for simulating peak demands and sizing much of the infrastructure, however is not sufficient for design or simulation of all parts of the system (e.g. sewage treatment plants).

Adding material flows adds considerable complexity to modelling, due to chemical reaction kinetics and increased data requirements. An example of a more detailed model, which simulates flow of 21 materials through runoff, sewer flow and sewage treatment is STORM/SEWSYS (Ahlman et al. 2005; Ahlman and Svensson 2005).

Some models reduce the complexity inherent in comprehensive material flows by eliminating chemical reaction kinetics. For example, sewage treatment plant performance may be estimated using a constant, user-defined removal efficiency for each material (eg. in models by Warhurst and Mitchell 2000; Fane et al. 2002; Rousseau et al. 2005). Other mass balances reduce complexity by including water plus one other material (eg. Jodicke et al. 2001 balances only water and phosphorus). WaterCress (Cresswell et al. 2002) does not simulate all material flows, instead delineates water quality using codes for different quality classes. These simplified material balances result in an inability to simulate changes in water/effluent quality due to: contaminant build-up in water recycle loops; change in consumer behaviour; change in technology or climate.

The materials and energy associated with manufacturing, constructing and operating infrastructure play a key role in LCA-style sustainability analyses, however are generally not integrated into engineering simulation models. Some models do simulate energy of operation, such as URWARE wastewater treatment plant models (Jeppsson et al. 2005), and various process engineering software packages (eg. Aspen Technology Inc. 2006; eg. Chemstations Inc. 2006).

Industrial ecology aims to optimise water use between neighbouring areas or users, and/or to optimise the way the water system interacts with the other interconnected industries (such as those which process sludge, produce/dispose/recycle materials of construction, and other utilities). The vast majority of water models are focussed just on water, occasionally on the dissolved substances and the energy of operation. Examples of industrial ecology in water are rare, and are based on selecting and comparing alternative scenarios, rather than optimising as per (van Schaik and Reuter 2003).

3.2.7 Optimisation

In most cases, urban water systems aren't mathematically optimised; instead a number of scenarios are selected, assessed, and ranked, using LCA or similar methods (eg. Warhurst and Mitchell 2000; Jodicke et al. 2001; eg. Butler et al. 2006). This process is clearly limited by the lack of guarantee that the optimum lies amongst the selected scenarios. The ranking of selected scenarios is sometimes referred to as optimisation in the literature (Beck 1997). Mathematical optimisation is a more powerful tool that is rare in urban water modelling.

One segment of urban water modelling that is often subject to least-cost mathematical optimisation is that of potable water supply and distribution (eg. Chavez-Morales et al. 1987; Dai et al. 1992; Feldman 1992; eg. Jenkins and Lund 2000). Another case of subsystem least-cost optimisation was conducted in wastewater treatment and reuse (Oron 1994). Subsystem infrastructure is regularly optimised on a least-cost basis, including design of distribution networks (Goulter 1992) and reservoir sizing (Lele 1987; Simonovic 1992).

No literature has been found on multi-objective mathematical optimisation in water, or of optimisation across the whole urban water system.

3.2.8 Integrated optimisation and dynamic simulation

The integrated use of optimisation and simulation has occasionally occurred in water system modelling, and the need for such an integration for water distribution networks has been expressed (Goulter 1992). The optimisation of irrigation water supply and cropping provided the structure for a simulation model of a farming district (Chavez-Morales et al. 1992). Optimisation and simulation models have been used iteratively in water distribution design (Lansey and Mays 1989). The integration of optimisation and simulation across larger segments of the urban water system has not been found.

3.2.9 Economics, environmental and social impacts

Economic cost, environmental and social impacts are not normally quantified as an integral part of engineering simulation models, rather are carried out separately after model simulation (eg. Warhurst and Mitchell 2000; eg. Apostolidis 2004). There are exceptions. Many of the subsystem software packages for sale include equipment costing (eg. Aspen Technology Inc. 2006), and some also include environmental impact assessment (eg. Intelligen Inc. 2005). The inclusion of impacts into the system model in this research is required, so these impacts can form part of the objective function in the integrated optimisation.

3.2.10 Models of the whole urban water cycle

No models have been found in this literature review, that cover the whole water cycle, through urban, rural, industrial, agricultural, engineered and natural environment. A number of models simulate the whole of the urban water cycle. A selection of these is reviewed here in further detail.

UVQ (Warhurst and Mitchell 2000) is a preliminary assessment tool for comparing alternative strategies for the urban water system. It estimates contaminant loads as well as water volume, and contains flexibility to simulate different structures, greenfield as well as retrofit. The authors acknowledge the limitations of simplifications made, such as: no reaction kinetics in water quality simulation; and a daily time-step, which prevents peak flow simulation. There is no optimisation.

WaterCress (Cresswell et al. 2002) is a feasibility screening tool for large water cycles incorporating towns and rural areas, irrigation, rainfall and runoff. Its water quality is estimated by labelling each stream with a quality code, and estimating salinity using a lumped conceptual module. Output data for decision making consist of: reliability of water supply; water quality code for each stream; and average cost. No optimisation is possible. Citing difficulty in converting system benefits into economic values, the authors prefer assessing selected scenarios to mathematical optimisation (WaterSelect P/L 2006).

Hydro Planner (Maheepala et al. 2005) is an integrated framework for assessing water and constituent flows at the city and regional scale. The structure uses an integration module to link many existing subsystem models, providing a whole-of-system approach. The integrated framework includes a subsystem module to optimise water allocation; however there is no system-wide optimisation. Hydro Planner is currently under development.

UrbanCycle (Hardy and Graedel 2002), also under development, uses a hierarchical network structure to integrate across spatial scales of the urban water system. The time step is sub-daily, and flexibility exists to explore the use of various water sensitive urban design measures. There is no optimisation.

3.2.11 Summary

There is a wide variety of urban water models, with different intended uses and capabilities. Research has moved towards encompassing the whole urban system into one model, however urban system models developed so far are applicable only as preliminary screening tools. Optimisation is carried out on a cost basis for a single subsystem, however there is no system-wide or multi-objective optimisation. There is a need for a system engineering simulation/optimisation tool which spans the urban water system, and which includes flows of all materials and energy, not just water. From this strong basis, optimisation of water systems across large scales (beyond just urban systems), and integrated with other related industries (industrial ecology) can then be carried out.

4 ENABLING CYCLIC FLOWS

4.1 CHARACTERISATION OF TECHNOLOGIES

Waste water is the product of water that has been used in applications such as washing; flushing; and manufacturing processes. This water can contain waste products such as organic matter, nutrients, chemicals, pathogens and metals.

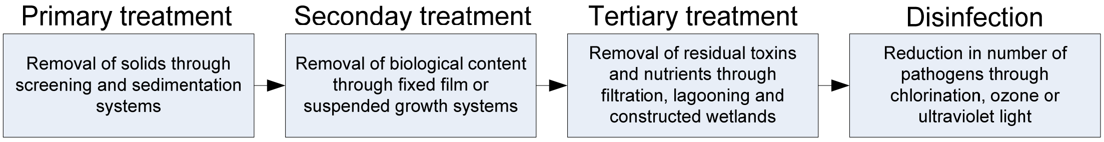
Treatment of waste water is undertaken to enhance the water quality for water reuse in other applications. This process utilises physical, chemical and/or biological processes to remove the waste products from the waste water stream.

There are several stages in waste water treatment. The first stage: primary treatment, involves the removal of sand, grit, and other settable solids, oils grease and fats from the water stream through the use of screening and sedimentation systems. The secondary treatment stage involves the removal of biological content such as human waste, food waste, and detergents from the waste water stream through the use of fixed film or suspended growth systems.

Often, the tertiary treatment stage in the treatment of waste water involves the removal of residual toxins, and nutrients such as phosphorus and nitrogen through the use of filtration, lagooning and constructed wetlands. However; if the treated waste water is to be used where there may be the risk of direct human contact, a disinfection stage is added to substantially reduce the number of pathogens still present in the water. Disinfection involves the use of chlorination, ultraviolet (UV) light or ozone (O_3).

The stages of waste water treatment are illustrated in Figure 4-1 below.

Figure 4-1: Typical stages in waste water treatment



There are many different waste water treatment technologies available for each stage of treatment. Technologies for each treatment stage range in specifications such as the systems treatment capabilities, cost, maintenance and labour requirements and size. A range of treatment technologies applicable to the secondary treatment stage are detailed below and a more detailed description of primary and tertiary treatments are outlined below.

4.1.1 Primary treatment technologies

Primary treatment utilises mechanical treatment technologies such as; strainers to remove the large objects; sand channels, where the velocity of the incoming waste water is slowed to allow for the settling, for removal of sand and grit; and sedimentation tanks to allow for removal of floating oils, greases and fats and removal of settled smaller particulates.

4.1.2 Secondary treatment technologies

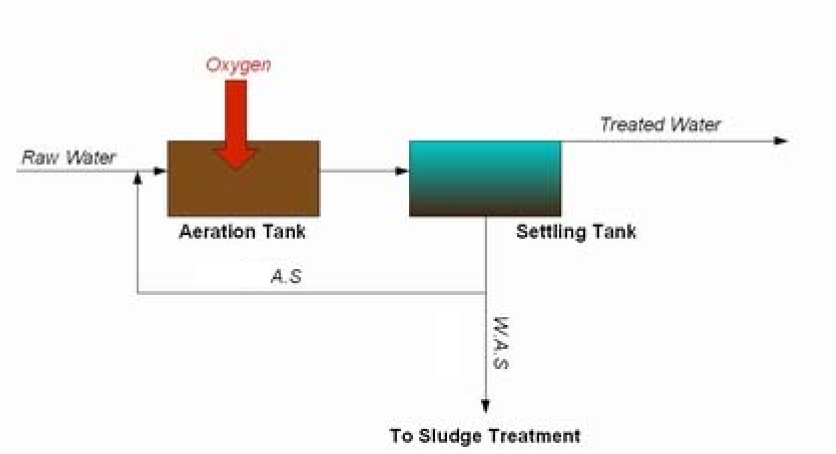
Secondary treatment utilise technologies such as activated sludge systems, rotating biological contactors and sequencing batch reactors. An overview of these three technologies is presented below.

► **Activated Sludge**

Activated Sludge is a process that involves aerobic treatment of liquid waste water (Figure 4-2 and Figure 4-3). It involves the mixture of primary effluent which settles solids from the settling tank to create a sludge mix. The production of an activated mass of micro-organisms acts to reduce the biological oxygen demand of the waste water (Spellman. F. 2003). This stabilisation and treatment of the water is achieved aerobically by typically using lagoons and machines to create a vigorous aeration process or by injecting compressed air into the sludge mix. After this aeration process the wastewater enters a settling tank where the treated water is separated from the sludge. The sludge is then sent off for further treatment or used again at the start of the process and mixed in with the primary wastewater to start the treatment process again (Metcalf. and Eddy. 1991).

Figure 4-2 Activated sludge system aerial view (SPG Media Limited. 2006a)

Figure 4-3 Activated sludge system (Wikipedia. 2006)



► Rotating Biological Contactors

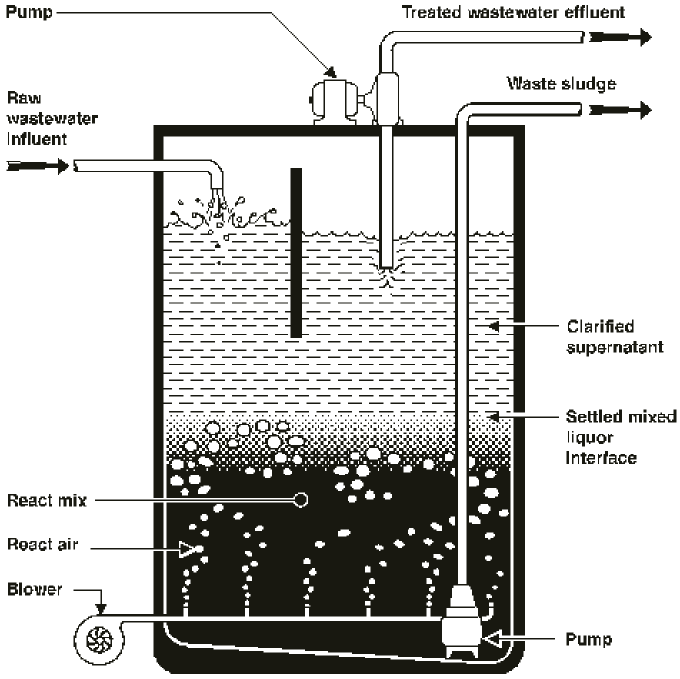
This treatment system involves the rotation of closely spaced circular disks of polystyrene or polyvinyl chloride through the waste water (Figure 4-4). When the disk rotates, the attached biomass film that grows on the disk surfaces moves through the wastewater. While moving through the wastewater, the micro-organisms absorb the organic material. Then, when it rotates out of the wastewater, oxygen activates aerobic decomposition. Any excess solids are transported with the wastewater to a settling tank where they are separated (Spellman. F. 2003).

Figure 4-4 Rotating Biological Contactors (Mission Green Canada. 2006)

► Sequencing Batch Reactor

This is a 'fill-and-draw' activated-sludge treatment system where the waste water is added to the reactor (Figure 4-5). The reaction then takes places and the solids allowed to separate and settle, creating a cleaner effluent on top (Metcalf. and Eddy. 1991). The Sequencing Batch Reactor is suited to treatment of wastewater which has low or intermittent flow conditions and to areas of restricted land area.

Figure 4-5 Sequencing Batch Reactor (Public Works and Government Services Canada. 2006)



4.1.3 Tertiary treatment technologies

Tertiary treatment utilise technologies such as membrane filtration. An overview of this technology is presented below.

► **Membrane filtration**

Membrane filtration involves the passing of a known volume of water through a membrane filter which, due to its small pore size, filters out all the bacteria and other solids. Different techniques based upon pore sizes are: microfiltration, ultrafiltration, nanofiltration and reverse osmosis (Spellman. F. 2003). Microfiltration is often used smaller water supply systems due to the steady decline in the cost of membrane systems and reliability of the technology (GHD. 2005). An example of the system in operation is illustrated in Figure 4-6.

Figure 4-6 Membrane-Filtration (SPG Media Limited. 2006)

4.1.4 Disinfection technologies

Disinfection involves the application of chlorine, ozone or ultraviolet light to the treated waste water. Chlorine disinfection is widely used due to its low cost, and it's effectiveness at eliminating pathogens. The application of chlorine involves dosing the water following tertiary treatment with a chlorine concentration tailored to the waste water characteristics. Chlorine disinfection works by oxidising cellular material and therefore kills all pathogenic micro organisms that may still be presented in the treated waste water.

Ozone disinfection is increasingly being used due to it's effectiveness at eliminating pathogens with minimal contact time and without the production of by-products foreign to natural water that chlorine produces (GHD and ITU 1995). Ozone disinfection works by exposing the waste water to ozone in a contact chamber.

Ultraviolet (UV) disinfection utilises UV radiation to deactivate the cell of pathogenic micro organisms.

4.2 ENVIRONMENTAL IMPACTS OF SUPPLY AND TREATMENT

Increasingly, individual consumers are looking to become more sustainable, which includes becoming more conscious of water use and reducing potable water use. There are different tools around Australia and internationally which assess the life cycle impacts for different water systems. These invariably aim to examine or assess the advantages and disadvantages of different water systems by looking at the life cycle impacts (Tangsubkul. N., Waite. T.D. et al. 2001). Material and energy inputs into the system are generally considered, as well as the environmental outputs, often through computer modelling (Stokes. J. and Horvath. A. 2005). However, all tools truncate the analysis to some extent, usually for reasons of data, practicality or simplicity. For example, the Water-Energy Sustainability Tool (WEST) does not include all environmental impacts such as emissions to land and water or some ecological effects or the extra cost associated with implementing the new system (Stokes. J. and Horvath. A. 2005).

Implementing the correct water reuse system, based on environmental life cycle assessment, has the potential to provide for reduced environmental impacts. Maximising water reuse and efficiency means less water will be needed from offsite, which will help to reduce the amount of water required in catchments. In turn, this will allow less human interruption to the water cycle. There will be less water discharged into the sewerage system, and the water that is discharged may be of a higher quality, which will mean there will be less treatment required to the water before it is discharged back into the natural environment (Chanan. V., White. S. et al. 2003). Life cycle assessment can focus on different environmental issues such as greenhouse gases or energy use so decision makers need to know what environmental issues are important for their decision making (Horvath. A. 2005).

While environmental life cycle impacts are often considered when looking into water reuse projects, other factors often override the analysis. The biggest external factors are economic, political, social and reliability concerns (Stokes. J. and Horvath. A. 2005). These factors, especially the economics, are often the final determinant of the suitability of a water system and environmental life cycle impacts are thus relegated in importance. As a result, environmental benefits are typically only likely to arise out of 'win win' options, providing both financial and environmental outcomes. Key issues for financial appraisal include the timescale, discount rate, and risk impacts relating to future security and cost of water supply. Despite the fact that many new water reuse systems involve a large upfront economic outlay, the long term savings need to be considered over the life of the system.

Water authorities have realised the potential for their operations as well as users of their water to reduce their environmental impacts (Water Resources Strategy for the Melbourne Area 2002). This is explored further in the next section.

5 CASE STUDIES

5.1 ECO INDUSTRIAL PARKS (EIPS)

An EIP is defined by the US EPA as:

> *A community of manufacturing and service businesses seeking enhanced environmental and economic performance by collaborating in the management of environmental and reuse issues. By working together, the community of businesses seeks a collective benefit that is greater than the sum of the individual benefits each company would realise if it optimised its individual performance only" (Martin, S. et al. 1996)*

EIPs are an application of both industrial ecology, in that waste exchanges occur in the vicinity of the park, and integrated chain management, a field defined by Vermeulen et al. (1995) as the management of material flows, in chains caused by social activities, with respect to the environmental space boundaries. While the field of integrated chain management is closely related to industrial ecology, a key distinction is found by analysing their spatial orientation. Integrated chain management, for example, can be applied at the national scale for a particular product, encouraging the take back of waste products and redesign to facilitate pollution prevention. By contrast, industrial ecology have a more localised application, usually resulting in co-located companies finding cost effective means of recycling or reusing waste streams. In industrial ecology, the regional element is the decisive factor, as opposed to the supply chain in integrated chain management.

5.1.1 Kalundborg EIP

The Kalundborg EIP is most commonly cited example of an attempt to pursue environmental initiatives within an industrial 'ecosystem'. Located in Denmark, the Kalundborg EIP is regarded as a relative success in the field, yielding economic benefits to all parties involved, with total economic benefits totalling between US $12-15 million per year (de Walle, 1996).

5.1.2 EIPs in US and The Netherlands

Heeres et al. (2004) conducted an assessment of six examples of EIP in the USA and the Netherlands with a view to explaining why Dutch case studies were, in general, much more successful than their US counterparts. According to the study, underpinning the success of the Dutch approach was a low level of government involvement and a high level of business buy-in. In the Netherlands, the idea of EIP emerged from the companies themselves as they saw the potential economic benefits of recycling and reuse. This translated to more active participation throughout the project life that yielded continual economic and environmental benefits. By contrast, the US examples were largely funded by the government, and therefore there was little financial commitment by the companies involved to realise the outcomes of the projects.

Heeres et al. (2004) also observed that the most successful EIPs began with utility sharing, or regional collaborations often in response to scarcity of water or energy, often achieve both high per dollar environmental benefits initially, and much greater productive collaboration in the long term. By contrast, projects that were limited to waste exchange specifically to meet pollution reduction targets contributed less to sustainability over the longer term, despite higher initial capital expenditure than utility sharing projects. The most commonly cited examples of successfully implemented project in industry are those that have emerged in this way, known as "natural" or "unplanned" EIP development and taken decades to flourish. Such examples are also known as Industrial Symbiosis.

5.1.3 The Circular Economy in China

China is a current example of a rapidly industrialising economy that has brought severe environmental consequences but also some innovations in greening industry. Over the past 20 years, some of the ideas of industrial ecology have taken hold in Chinese industry and government. The concept of the 'circular economy' originated in 1998 by Chinese Scholars and was formally adopted by the central government as a new development strategy and will be one of the underpinnings of Chinese development in the 21st century (Yuan et al., 2006). The basis for the Circular Economy (CE) is the closed loop flow of materials and energy commonly cited in industrial ecology literature. CE shares and seeks to apply concepts from across industrial ecology, cleaner production, ecological modernisation, green supply chain management and green building.

The literature reports on a three-tiered approach to the implementation of CE principle in China, the firm level, the EIP and the eco-city or eco-province. At the individual firm level, in the construction of eco-industrial networks and at the city or province wide level. Between industrial firms, local environmental protection authorities have established a public disclosure system of categorising company's based on their environmental performance.

At the eco-industrial level, synergies between production systems are developed that promote environmental protection. This is exemplified in EIPs, of which there are more than 100 in China (Yuan et al., 2006). State owner sugar company, The Guitang Group, leads the development of EIPs in China with a complex of industries developed around each of its factories that recycling and reuse sugar production by products. Finally, the concept of the eco-city, or eco-province is gaining momentum in China, with Shanghai becoming the country's leader in pursuing a closed loop economy, highlighted in the Shanghai Tenth Five-Year Plan for Socio-economic Development (2001-2005) (Shi *et al.*, 2003).

The development of CE in China has brought a number of different perspectives to bear upon the approaches and projects that are being implemented. The prevalence designs borrowed from previous projects without adaptation to context specific realities is a common cause of difficulty (Yuan et al. 2006). Recently, reactions to some problematic projects and the desire to further roll-out the environmental benefits of CE has prompted a shift to more broad adjustments in the structure of industry. This includes reforms of policy and regulations, which is considered a progression from more limited waste recycling projects.

5.2 KWINANA INDUSTRIAL AREA

5.2.1 Overview

Western Australia is the largest and most sparsely populated state in Australia. The State has rich natural resource endowments, including - but not limited to - iron ore, bauxite, gold, nickel, mineral sands, diamonds, natural gas, oil and coal. Heavy process industry is concentrated in a few industrial areas, of which the Kwinana Industrial Area (KIA) is the largest and most diverse. KIA was established in the 1950's following a special Act of Parliament, which secured an area of about 120 km^2 to accommodate the development of major resource processing industries in Western Australia. Kwinana is located 40 km south of the capital city of Perth on the shores of Cockburn Sound, a sensitive marine environment.

Kwinana's many features make it a world-class industrial area. Its deep-water port is capable of handling bulk cargo, a thirty minute freeway-drive links the estate to Perth's central business district and the estate is linked via road and rail through the Fremantle container port to the eastern states of Australia, South East Asia and the rest of the world. About 3,640 people work in the area's core industries, and many more in related sectors and service jobs. The total economic output of the area exceeds A$4.3 billion annually (SKM 2002). With its concentration of industries and close proximity to the coast, the Kwinana industrial area plays a very important role in the economy of Western Australia, and in the local community. KIA has long been recognised as a cornerstone of the Western Australia's economy (SKM 2002).

The Kwinana Industrial Area is home to a diverse range of industries ranging from fabrication and construction facilities through to high technology chemical and biotechnology plants and large resource processing industries, such as titanium dioxide pigment production and alumina, nickel and oil refineries. There is considerable integration between these industries. A number of companies produce essential raw materials for the manufacturing and refining processes of other nearby enterprises.

In 1991 the core industries established the Kwinana Industries Council (KIC). Its original purpose was to organise collectively the required air and water monitoring for the industries in the area, in response to increased government and community pressure to manage the air- and watersheds, and protect the sensitive marine environment in the adjacent Cockburn Sound. The KIC now addresses a broad range of issues common to Kwinana's major industries (including water efficiency, consumption, discharge, and recycling), and seeks to foster positive interactions between member companies, government, and the broader community.

5.2.2 Importance of Water

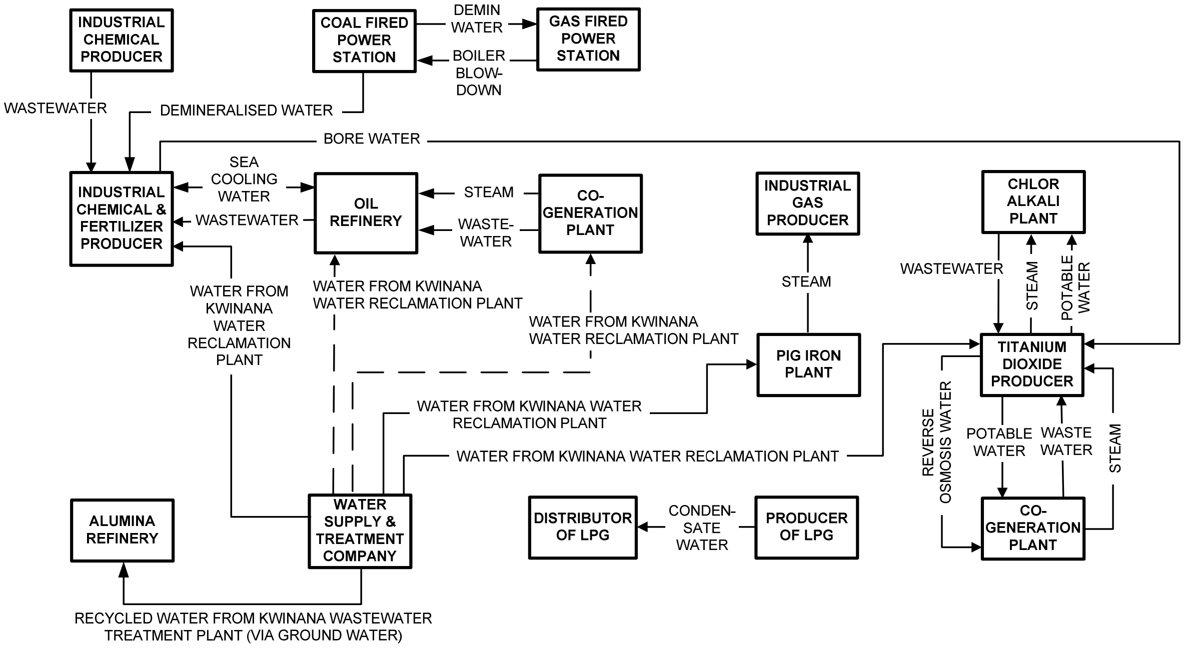
Water consumption and effluent disposal by Kwinana businesses are key environmental issues addressed by the KIC. Over the past years, significant progress has been made towards the improvement of water consumption and disposal in the Kwinana region, both at the company level (e.g. on-site water efficiency assessments at various KIC member companies) and at the regional level (e.g. Kwinana Water Reclamation Plant, described in next section). Individual Kwinana companies had achieved major water savings prior to engaging in water synergies, e.g. Tiwest Pigment Plant, CSBP, and BP Refinery (DEH 2001; DEH 2001d; WASIG 2005). Due to declining levels of groundwater and stored water in Perth Metropolitan dams, fresh water will be a more scarce resource over the next decades and the cost of water is likely to increase over time. Runoff into dams has been reduced by 40-50 percent since 1975 because of decreased rainfall. The State Water Strategy includes a water re-use target of 20% by 2012 (GoWA 2003). The government will require major water users to demonstrate their responsible use of water by setting up and implementing water resource management plans. So there is a need to further investigate the opportunities for improving water efficiency and effluent disposal within the KIA due to declining water supplies, increasing external pressure from government and other stakeholders, and anticipated expansion plans for the industrial region.

5.2.3 Existing Water Synergies

The case-study presented here illustrates the tight collaboration and integration of industrial activity in the Kwinana Industrial Area. This has historically developed in response to perceived business opportunities, and to environmental and resource efficiency considerations. This maturity of industry collaboration provides testimony for the contribution regional resource synergies can make to sustainable development at the regional scale (van Berkel 2006). The number of existing regional synergies, including water utility synergies, in Kwinana compare favourably with well-regarded international examples, for example Kalundborg in Denmark and Rotterdam in The Netherlands. This positions Kwinana well among the leading edge examples of regional resource synergy development in heavy industrial areas (Bossilkov et al. 2005).

The recently updated inventory of existing regional synergies (van Beers et al. 2005) showed that these are quite diverse in Kwinana. There are 47 synergy projects in place, including 32 by-product synergies and 15 water and energy utility synergies. The inventory was compiled from industry surveys, and is therefore not necessarily complete. The current water utility synergies in Kwinana are graphically presented in Figure 5-1.

Figure 5-1: Current water synergies in the Kwinana Industrial Area Modified from: (Van Beers et al. 2007)



Some illustrative examples of water utility synergies in Kwinana are (van Beers et al. 2005):

- Reuse of recycled effluent at alumina refinery: Treated wastewater from Kwinana Wastewater Treatment Plant is infiltrated into groundwater upstream from Alcoa groundwater extraction bores. The bores supply water for Alcoa's process water circuit for the Kwinana alumina refinery. Thus the discharge from Kwinana Wastewater Treatment Plant is indirectly used for reuse by Alcoa and is estimated at 1100 ML/yr.

- Chemical plant supplying bore water to pigment plant: Tiwest established its pigment plant in the KIA at a time when the groundwater allocation for the area had already been licensed to the existing industries. Their process initially required a significant amount of scheme water. In addition to vigorous water efficiency achievements, which have seen the specific water consumption per ton of pigment drop to less then half, Tiwest now supplements scheme water intake with 1400 ML/yr of CSBP groundwater supplies, allocated by the State's authorities.

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

- Kwinana Water Reclamation Plant: The Kwinana Water Reclamation Plant (KWRP) is a joint initiative of the Water Corporation and the Kwinana industries. It achieves the double benefit of greater overall water efficiency and reduced treated process water discharges into the Cockburn Sound. A micro filtration/reverse osmosis unit was built, at a cost of approximately A$30 million, which takes secondary treated effluent from the nearby Woodman Point wastewater treatment facility to produce a low total dissolved solids (TDS) water supply. This water is or will be used by CSBP, Tiwest, Kwinana Cogeneration Plant, BP and HIsmelt to replace scheme water. This will replace 6000 ML/yr, about 2-3% of the total scheme water use in the drought-affected Perth metropolitan area. The low TDS enables the process plants to cut their use of chemicals in cooling towers and other process applications, thereby reducing metal loads in their effluents. In exchange for taking water from the KWRP, the industries will be able to discharge their treated effluents into the deep ocean outfall through the Water Corporation pipeline. This will eliminate the current discharges of treated process water into the sensitive Cockburn Sound (Water Corporation 2003).

5.2.4 Benefits of Regional Synergies in Kwinana

The key to the development of regional water synergies is that there is an overall net benefit from the synergy without any of the synergy participants being disadvantaged. The types of benefits can vary greatly and often go well beyond the conventional business case benefits. Sustainability benefits of the water synergy examples presented in the previous section are provided in Table 5-1. The common element for most of these water synergies is better water source security through utilisation of an alternative water stream that would otherwise be discharged into the environment. Reducing industry vulnerability with regard to future droughts and water shortages can be considered as one of the main reasons for developing these synergies. All presented synergies have environmental and community benefits such as water conservation due to greater water efficiency, and lower impact of discharged treated effluent on ecological integrity and community amenity value of the Cockburn Sound. The examples show that the benefits are not just commercial but also strategic, leading to reduced exposure to risk and better reputation with key stakeholders including government and community (Corder et al. 2006).

Table 5-1: Estimated benefits of selected existing water synergies in Kwinana (Van Beers et al. 2006)

Synergy	Economic impacts			Environmental and community impact		
	Water purchase costs	**Wastewater treatment plant and disposal costs**	**Greater water security**	**Water conservation**	**Quality of discharged effluent**	**Impact of discharged effluent on environment and community value**
Reuse of recycled effluent at alumina refinery	Same	Same	Yes	Yes	Same	Same
Chemical plant supplying bore water to pigment plant	Lower	Same	Yes	Yes	Same	Same
Artificial wetland treatment at chemical plant	Same	Higher	No	No	Higher	Lower
Kwinana Water Reclamation Plant	Higher	Lower	Yes	Yes	Same	Lower

5.2.5 Unique Features of Kwinana

A number of factors are unique to Kwinana and these have without doubt contributed to regional synergy developments in the area. These include (Van Beers et al. 2007):

- the diverse blend of key processing and manufacturing industries primarily producing for international markets with limited local competition between companies operating in the area,
- the relative isolation from other major industrial centres in Eastern Australia and internationally,
- a member-based industry organisation (Kwinana Industries Council) which addresses a broad range of issues common to the industries in the area,
- the proximity to Perth as a major metropolitan centre,
- the gradual urban encroachment around the industrial area, and
- the growing recognition for the natural resource value of the Cockburn sound on which shore the Kwinana Industrial Area is located.

Key industries and the Kwinana Industries Council have made it a strategic priority to move towards the next level of resource synergies in Kwinana.

5.2.6 Progressing New Synergy Opportunities

Fresh water has already become a scarce resource as a result of declining levels of groundwater and stored water in Perth dams. This is likely to result in the costs of water increasing over time, and also in increasing external pressure to reduce fresh water consumption. There is widespread commitment from the industries in Kwinana to achieve greater water efficiencies and synergies, thereby making a contribution to sustainable water use in the area. Many and diverse water synergy opportunities still appear to exist with regard to bilateral water synergy opportunities (direct between two companies) and collective water synergy projects between multiple Kwinana companies. Potential water synergies will come to fruition through hands-on support and dedicated research to identify, screen and package the available technologies and quantify the potential synergy benefits.

The Centre for Sustainable Resource Processing (www.crsp.com.au) commissioned the Kwinana Synergies Project to provide practical assistance to the Kwinana industries to identify, evaluate and implement synergy opportunities (van Beers 2006). This research is being conducted in close collaboration with the Kwinana Industries Council (KIC) through the Centre of Excellence in Cleaner Production at Curtin University of Technology. One of the focus areas of the KIC and the Kwinana Synergies Project is to further enhance water use and wastewater discharge practices. As part of this work, baseline assessments of water inputs and outputs have been conducted for ten major water consuming companies, including brainstorming sessions with company staff on opportunities for exchanges of water between industrial operations, joint water treatment, and joint storage of water (Van Beers et al. 2006). Current research efforts focus on providing industry assistance to progress the one-on-one synergies short-listed at a KIA water synergies workshop, and scoping ways forward for the further development of four collective KIA water synergies. These collective synergies include the reuse of treated effluents as separate streams or as an aggregated source, reuse of boiler blowdown from power generation, and the further development of the Kwinana Water Reclamation Plant (assessed by the Water Corporation).

Parallel to the hands-on synergies work with the Kwinana industries, a toolkit, which is part of the Regional Eco-Efficiency Opportunity Assessment Methodology (Bossilkov and van Berkel 2005), has been developed. This toolkit is discussed elsewhere in this literature review.

5.2.7 Success factors for Regional Synergies

A recent review of international case-studies conducted as part of an Australian Research Council funded regional synergies research project (van Berkel 2006) concluded that the realisation of successful synergies is dependent on three main aspects: proven technology, convincing business case, and 'license to operate'. Over the past decade water treatment through reverse osmosis has become a viable technology to enable water utility synergies, as illustrated by the Kwinana Water Reclamation Plant. In terms of business case, there must be compelling evidence that financial and other business benefits outweigh the project costs and risks involved. The decision to implement a synergy becomes more difficult when the business case does not meet the financial criteria but would produce other significant but 'less tangible' benefits, in areas such as reputation, environment or community. These 'softer' benefits can be a strong driver for change and are usually much more difficult to control than associated technologies (Corder et al. 2006). If, for instance, the local community perceives an industry is having undesirable impact on their lifestyle through effluent discharges or large consumption of scheme water, even if the company is satisfying the government regulations, this could affect the company's 'licence to operate'. This can drive the development of regional water synergies. This is illustrated by the reduced use of scheme water by the Kwinana industries through sourcing industrial water from the Kwinana Water Reclamation Plant, municipal wastewater treatment plants or neighbouring industries.

When comparing Dutch and US EIP development projects Heeres et al. (2004) identified factors essential to the success or failure of EIP development projects. One factor common to the successful Dutch projects was that the companies were active participants, being willing to provide resources to the development of the EIP. Another common factor was the presence of an entrepreneurs or employers association, which provided information and improved communication between companies. Other factors identified were existing energy, waste and material exchanges between companies, active participation of local residents and cooperation between local and regional government. The most frequently identified reason for failure was a lack of company interest. Reasons for the lack of interest included distrust towards the government (who established EIP plans) and a perceived financial risk. Other reasons for failure were the absence of an association to represent all companies, a relatively large distance between companies and lack of enough financially strong companies in the area (or willing to move there).

5.3 MELBOURNE CASE STUDY

CH2 SIX STAR GREEN BUILDING

Melbourne City Council's new CH2 building is a world leader in green buildings and shows what can be done with commitment to the state of the art. The building incorporates many beneficial energy efficient and low environmental impact technologies and design elements.

As a result, CH2 has become Australia's greenest building; the first to obtain a conditional 6 star Green Star rating from the Green Building Council of Australia. The environmental footprint is much lower than a standard building. Further benefits from the green building include a potentially happier, healthier and more productive workforce. The key features highlighted in this case study are those related to water saving.

CH2 PROJECT HIGHLIGHTS:

- **World leadership doesn't have to cost the earth**
- **Water mining –reclaiming water from public drains – is now proven to work in Victoria, providing major savings on both supply and wastewater**
- **By using readily available AAAA fittings and good design, water use savings in offices can be significant**
- **Even sprinkler system test water is saved and reused**

72% water supply savings make CH2 an example for other office buildings to follow

The new water treatment system collects all waste water from the building and supplements this with wastewater drawn from the city sewerage system. This 'sewer mining' allows the onsite system to clean up to 100kL/day for recycling, thus reducing mains water supply by 72%.

CH2 illustrates how council and government can lead the way in sustainable architecture, while emphasising both its desire to provide healthy work environments for employees, and environmental impact reduction for all. Through CH2, Melbourne City Council took it upon itself to set an example to the community and has done so by building a world leading environmental building.

5.3.1 Context

The decisions to build CH2 originated with the need for more office space. Rather than build a conventional building, Melbourne City Council seized the opportunity to demonstrate its commitment to sustainability. It has clearly succeeded, creating Australia's greenest and healthiest office building in the process.

Technologies are evident throughout, from the sewer-mining plant in the basement, phase-change materials for cooling, automatic night-purge windows, wavy concrete ceilings, a façade of louvres (powered by photovoltaic cells) that track the sun – even the pot plant holders have involved a whole new way of thinking.

5.3.2 The Project

► On-site treatment ('water mining' or 'sewer mining')

A laser drill was used to provide access to a City sewer main from the basement of the building. About 100,000 litres of water a day is extracted from the main sewer though this link. The sewer water typically contains 95 per cent water, and the 'water mining' technology allows the removal of this water, while returning the solids to the sewer system.

The key technology in the water mining systems is the Membrane Water Re-Use (MWR) water treatment technology. This is essentially a three-stage filtration process: a 200-micron pre-screen, a dual-membrane ultra-filtration stage and a reverse osmosis process. MWR is unlike biological treatment plants which involve inherent odours, size and complexity. MWR is compact, largely chemically free, and low-maintenance in operation.

► Membrane Water Re-Use Technology

The first step in the process is 200 micron stainless steel mesh pre-screen, through which the sewage passes by gravity to the ultra-filtration feed tank. This pre-screen removes gross suspended solids (mostly fibrous materials), oil and grease. Water sprays periodically wash the solids (screenings) from the screen back to the sewer. Hence, there is no handling of the screenings or biomass storage.

The second step, 'ultra-filtration', is achieved with cross-flow configured tubular ceramic membranes which contain microscopic pores around 0.02 micron in size. The pre-screened sewage is continuously filtered through these membranes and the filtered water is collected from the outside of the ceramic membrane. The bulk of the bacteria and viruses will not pass through this membrane and will therefore be removed at this stage. As with screening, all solids that accumulate on the membrane are periodically backwashed and returned directly back to the sewer. The membrane is automatically cleaned as required (about every 15-30 days) with hot water and additional cleaning solutions as required, to maintain performance.

The third step is Reverse Osmosis, which uses a semi-permeable membrane to separate and remove remaining dissolved solids, organics, pyrogens, submicron colloidal matter, viruses, and bacteria from the water. The process is called "reverse" osmosis since it requires pressure to force pure water across a membrane, leaving the impurities behind. Reverse Osmosis is capable of removing 90% - 95% of the total dissolved solids (TDS) and 99% of all pathogens, thus providing safe, pure water.

► Water management in CH2

The MWR plant water and rain water collection will supply all CH2s non-drinking water needs, including water cooling, plant watering and toilet flushing. Excess treated water will be used in other council buildings, city fountains, and gardens. Using the MWR system will reduce CH2 mains water supply requirements by 72%. Of course, sink and toilet waste water from CH2 is also fed into the MWR for recycling.

In addition, CH2 is designed to be a low water use building. To reduce water consumption, all water fittings have AAAA ratings, all toilets are dual flush, and all urinals have sensor-triggered flushing. About 25 per cent of potable (drinking) water will come from the sprinkler system used for fire safety. Safety regulations require that sprinkler systems are tested regularly and this typically involves discarding large quantities of clean drinking water. In CH2 this water will be collected and used.

5.3.3 Learnings and Outcome

Presented with the need to find more office space, Melbourne City Council took the initiative to put its environmental credentials into action with a building that was at once innovative, creative, technologically advanced, and environmentally sustainable, while setting an example for others to copy.

While CH2 did cost slightly more than a 'standard' building, it dispels the myth that new technologies and sustainable buildings are too hard or costly. As a result there is already considerable interest in using water mining technology (and other CH2 technologies).

The 'payback' for CH2 is estimated to be 10 years. However, in the meantime, further benefits from day one include:

- increased workplace effectiveness;
- lower costs for other public infrastructure; and
- the value of building as a guiding light in sustainable buildings.

5.3.4 Evaluation

Key Statistics	
Location	Melbourne CBD
Type of operation	Offices
Project type	Green Building
Start and completion date	Completed in 2006
Reticulated water savings	
Water reuse	100kL/day
Water treated	100kL/day
Other env issues	

5.3.5 Other Melbourne Case Studies

In addition to the commercial case study outlined above, there has been work undertaken historically in the industrial sector. Contact with stakeholders in industry (e.g. Australian Vinyls), government (e.g. DSE, EPA), utilities (e.g. SEW, CWW) and industry associations (e.g. PACIA) have provided anecdotal evidence of activities in this area and additional information will be sourced through the stakeholder workshop in May.

6 MELBOURNE CONTEXT

This section explores the Melbourne context for the application of industrial ecology opportunities.

Industrial, commercial and institutional sectors have not yet been targeted to reduce their water use, despite the fact that they often use large quantities of potable water and discharge large amounts of trade waste. About 28% of Melbourne's potable water use is used in the commercial and industrial sectors (Water Resources Strategy Committee for the Melbourne Area. 2001). Much of this use of potable water can be avoided or reduced by water reuse.

Water quality requirements vary significantly across the commercial, industrial and institutional water sectors. Despite needs for different grades of water (often at a lesser standard than reticulated water), the majority of water users from these sectors continue to use reticulated water as a primary source.

A key strategy for reducing demand on reticulated supplies is to engage with these sectors and to encourage the utilisation and reuse of water in a more effective and efficient manner. This can be achieved by encouraging the use of reclaimed and recycled water. Studies have shown how by implementing water recycling programmes, industries can save up to 50% on bought water intake which also reduces trade wastes and flow-on effects for the environment, economically and socially (Gumbo. B., Mlilo. S. et al. 2003).

6.1 CURRENT LANDSCAPE OF POLICY AND PROGRAMS

The potential areas of application of industrial ecology principles are broad, of interest here are:

- the policy context: Policy and regulations that constrain or enable industrial ecology opportunities in Victoria; and,
- existing initiatives: Key examples of collaborative initiatives in industry and government that have resulted in industrial ecology.

6.1.1 The Policy Context

The Australian and Victorian Governments, DSE and the EPA have developed a range of policies, guidelines and plans that set the direction for the management of industry water and wastes and are therefore relevant to this project. Specific legislation or standards for industry are beyond the scope of this section.

▶ **National Water Initiative (COAG, 2004)**

The National Water Initiative is a strategy driven by the Australian government and signed by the Council of Australian Governments (COAG) to improve water management across the country. In response to a worsening drought and Australia's highly variable weather patterns, coupled with the prospect of more than a million extra people settling in each of Sydney, Melbourne and South East Queensland, this strategy seeks to maintain economic, social and environmental wellbeing while continuing economic productivity.

Clause 66 of the National Water Initiative pertains specifically to elements of industrial ecology. This clause is reproduced below:

Water Storage and delivery pricing

66. In particular, States and Territories agree to the following pricing actions:

> *iii) review and development of pricing policies for trade wastes that encourage the most cost effective methods of treating industrial wastes, whether at the source or at downstream plants, by 2006;*

▶ Our Water Our Future (DSE, 2004)

In 2004, the Victorian government released Our Water Our Future, a vision for the water future of Victoria over the next 50 years. The Our Water Our Future white paper sets out 110 new initiatives of water conservation for residential and non-residential users of water. The paper accounts for population increases and climate change to ensure water security is maintained in future. Some of the key foci of the paper are to:

- repair rivers and groundwater systems by giving them legal water rights and conducting restoration works;
- price water to encourage water conservation;
- implement other water conservation and recycling initiatives;
- secure water for farms through water allocation and trading systems; and,
- incorporate community engagement strategies into water decision making through appropriate consultation as outlined in the Our Water Our Future green paper.

Sections of the white paper that are relevant to industrial ecology are the sections relating to Trade Waste. The document states:

> *Trade waste management will be consistent with an ethic of water conservation, and facilitate water and biosolids recycling. Trade wastes will be managed to reduce the impacts of discharges from wastewater treatment plants on the environment.*

Pursuant to this policy statement was Action 5.31, which states:

> *The government will review the state's trade waste management framework to reduce environmental impacts, facilitate water and biosolids recycling and support water conservation.*

There are also some specific initiatives outlines such as the salt reduction strategy for the Western Treatment Plant. Melbourne Water and City West Water are required to recommend strategies to reduce salt concentrations for 40% by 2009 through onsite or offsite treatment, or cleaner production strategies.

▶ Central Region Sustainable Water Strategy (DSE, 2006)

In 2004 the Victorian government developed the Pathways to Sustainability top 200 program to encourage high water users to analyse their water use and look for opportunities for water conservation. The Central Region Sustainable Water Strategy (see action 3.13, 2006) reported that this program resulted in 6,000ML of water being saved annually, which is the equivalent of 13.3% of total industry water use n Melbourne. Recently this program has been revised to include all businesses using 10ML or more (about 1500 users) and recommended that the program be revised to include regional businesses and particularly power generators and producers who are significant users in the central region. The forecast for savings from the revised program is more than 6,700 ML/a, with a particular focus on recycling in industry.

▶ Trade Waste Review: Issues and options White Paper (DSE, 2005)

The Issues Paper describes the current trade waste system and examines the impact of current management practices on resources and the Victorian economy. The Issues Paper aims to promote discussion on long-term options for improving trade waste management.

Included in the review are a map of baseline information on industrial processes leading to waste generation, the impacts of trade waste of resources and the economic significance of key industry sectors and their benefits to Victoria. One of the objectives of the trade waste review is to identify opportunities for water and biosolids recycling from trade waste or treatment plants.

The final report for the review is due to be released late 2007, but the issues and options paper (DSE, 2005) describes the overall direction of the review and identifies the key areas for improvement and their associated priority levels. A detailed gap analysis of trade waste management against DSE's sustainability framework provides a good introduction to some of the key shortcomings that may be overcome by particular industrial ecology initiatives.

▶ Industrial Waste Strategy (EPA, 1998) and Cleaner Production Partnerships Program

The Industrial Waste Strategy superseded the 1986 plan to minimise industrial waste, adding several significant components, including an acknowledgement that cleaner production should be at the centre of the industry approach to waste avoidance. The 1998 strategy looks beyond compliance to focus investments on optimising both environmental and economic outcomes. The strategy adopted three basic objectives:

- To achieve the widespread avoidance of waste by facilitating the adoption of cleaner production policies and practices;
- To maximise the economic value of resources during their life cycle through reuse, recycling and energy recovery in preference to disposal; and
- To foster a culture of continuous improvement in the waste management industry to achieve and maintain best practice in the management of residual waste streams in Victoria.

A Cleaner Production Partnerships Program is run by the EPA, and usually links with a peak body or water utility and an individual company. The program offers funding to qualifying businesses for waste and environmental assessments, studies to assess site-specific cleaner production issues and preparation of waste management or more holistic environmental management plans. Energy use is also an important component of this program.

▶ Water quality and treatment requirements

There are only a limited number of water quality reuse guidelines available in Australia and the world pertaining to commercial, industrial and institutional applications. A relevant example is EPA Victoria's guidelines for environmental management – use of reclaimed water (EPA Victoria. 2003).

EPA Victoria's document sets out guidelines for the treatment and use of reclaimed water, risks and responsibilities associated with treated water use, monitoring and reporting as well as providing information about the environmental benefits of the water reuse (EPA Victoria. 2003). As Table 6-1 shows, the guidelines indicate those elements that constitute the different classes of reuse water, how each water class is achieved and what the use of the reclaimed water reuse may be. Table 6-2 provides a glossary of terms used in Table 6-1.

Table 6-1: Water quality and treatment (EPA Victoria. 2003)

Class	Water quality objectives – Medians unless specified	Treatment processes	Range of uses- uses include all lower classes
A	Indicative objectives • <10.E.coli org/100 mL • Turbidity <2 NTU • <10/5 mg/L BOD/SS • pH 6-9 • 1 mg/L Cl residual (or equivalent disinfection)	Tertiary and pathogen reduction with sufficient log reductions to achieve: • <10 E.coli per 100 mL; • <1 helminth per litre; • <1 protozoa per 50 litres; & • <1 virus per 50 litres.	Urban (non-potable): with uncontrolled public access Agricultural: eg human food crops consumed raw Industrial: open systems with worker exposure potential
B	• <100 E.coli org/100 mL • Ph 6-9 • <20/30 mg/L BOD/SS	Secondary and pathogen (including Helminth reduction for cattle grazing) reduction	Agricultural: eg dairy cattle grazing Industrial: eg washdown water
C	• <1000 E.coli org/100 mL • Ph 6-9 • <20/30 mg/L BOD/SS	Secondary and pathogen (including Helminth reduction for cattle grazing) reduction	Urban (non-potable): with controlled public access Agricultural: eg human food crops cooked/processed, grazing/fodder for livestock Industrial: systems with no potential worker exposure
D	• <10000 E.coli org/100 mL • Ph 6-9 • <20/30 mg/L BOD/SS	Secondary	Agricultural: non-food crops including instant turf, woodlots, flowers

Table 6-2 Glossary of terms (EPA Victoria. 2003)

Term	Meaning
BOD	Biochemical oxygen demand - a measure of the amount of oxygen used in the biochemical oxidation of organic matter. The BOD test is typically conducted over a period of five days under specified conditions and may then also be referenced as BOD5.
E.coli	Escherichia coli. A bacterium found in the gut of warm blooded animals that indicates faecal contamination.
NTU	Nephelometric Turbidity Unit — unit of measure of the turbidity of water due to suspended, colloidal and particulate matter.
Pathogens	Organisms capable of causing disease. In untreated sewage, the key potential pathogens are bacteria, viruses, protozoans and helminths.
SS	Suspended Solids.

6.1.2 Existing Initiatives

▶ Environmental Protection Authority (EPA): Sustainability Covenants

Sustainability covenants are voluntary agreements through which EPA and a company, a group of companies or an industry sector can explore new creative ways of reducing the environmental impact and increasing the resource efficiency of their products and services.

Sustainability Covenants have the benefits of being able to focus on issues such as product design and broader business, social and environmental considerations rather than simply focussing on point source management. As such, the covenants provide a policy instrument that compliments the other tools that are included in the *Environmental Protection Act* (1970).

The key features of the sustainability covenants are to offer organisational statutory recognition for commitment to the environment through efforts to achieve more significant resource efficiencies. The covenants help to drive partnerships between government and industry and to encourage innovations that offer economic and social benefits to the wider Victorian community.

The sustainability covenant is best described by examples such as those held by VECCI, City West and PACIA.

Example 1: VECCI Grow me the money

Agreed by the EPA and Victorian Employers' Chamber of Commerce and Industry (VECCI), this covenant aims to increase the efficiency of member organizations and reduce the ecological impacts throughout the project lifecycle of its members.

The EPA has committed to providing $3 million over the period 2005/6 to 2007/8 to participating businesses. The outcomes of this initiative include, but are not limited to:

- a web based support tool for tracking the triple bottom line of businesses;
- a help desk with ongoing support for environmental issues;

- develop industry specific life cycle information and measurement and assessment tools; and,
- support for and facilitation of supply chain initiatives.

Example 2: Australian Industry Group (AIG)

The EPA and AIG signed a sustainability covenant to help AIG's 4000 member business integrate sustainability principles into their businesses. AIG represents businesses from the manufacturing sector such as metals finishing, food, paper, printing, packaging, automotive, and textiles. The EPA have agreed to a $3 million provided over 3 years.

The covenant will give AIG members the opportunity to shape their own sustainability framework in a public forum and to recognise developments made in the area of sustainability.

Example 3: Lend Lease

The lend lease sustainability covenant concluded on the 1/12/05 after completing the planned 1 year duration. The covenant enables lend lease to undertake strategic planning that incorporated sustainability principles. Some of the activities included in operationalising the covenant included:

- mechanisms for monitoring and public reporting of sustainable investment-related activities in a public format
- support of undertakings in sustainability reporting and broader stakeholder consultation
- develop sustainability measurement tools for their businesses, including a retail-specific eco-footprint tool
- publicly reward the efforts of retailers in the area of sustainable business operations
- trialling of embedded-technology pilot installations (including vertical composting technology, sewer mining and solar panels), either in new or existing assets
- potential retro-fitting for all centre management offices so that potential tenants can see energy and water efficient fittings in situ and more easily chose them for their tenancies.

▶ Essential Services Commission (ESC) Memorandum of Understanding with EPA

The ESC is the independent economic regulator for Victoria's utilities including electricity, gas, ports, grain handling, freight rail, taxi, hire car, tow truck, statutory insurance and water industries.

In 2003, one year after the ESC came into operation, an MOU was entered into by the ESC and the EPA with the key objective of ensuring that economic regulation of ESC's utilities is applied within a framework that is cognisant of the statutory requirements of the EPA. The ESC and the EPA have regular meetings to ensure this is being carried out, particularly with respect to water.

▶ Sustainability Victoria Resource Smart Businesses Program

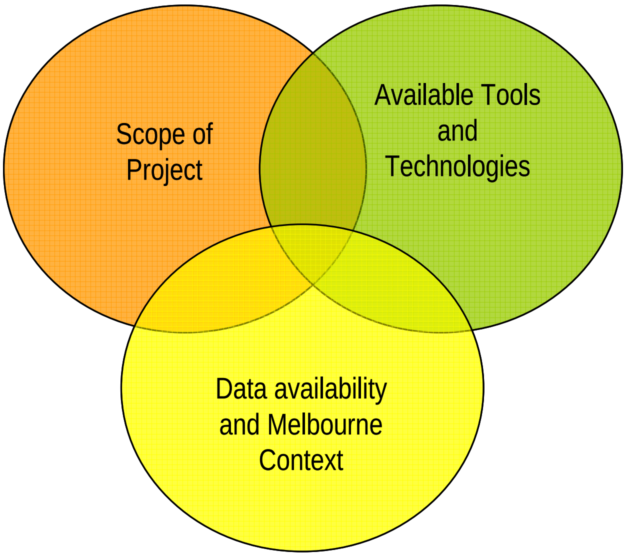
The Resource Smart Business Program administered by Sustainability Victoria supports businesses interested in delivering sustainable outcomes with regard to energy, materials and water use. The program offers $2 million, with set amounts allocated for businesses that demonstrate they will contribute their own funding. Specifically, the program will fund:

- assessment and benchmarking up to $15,000 matched dollar for dollar;
- innovation up to $150,000 matched dollar for dollar;
- infrastructure up to $350,000 matched 2:1; an,
- supply chain and industry solutions, with the amount dependant on partnership objectives.

6.2 DATA AVAILABILITY IN MELBOURNE

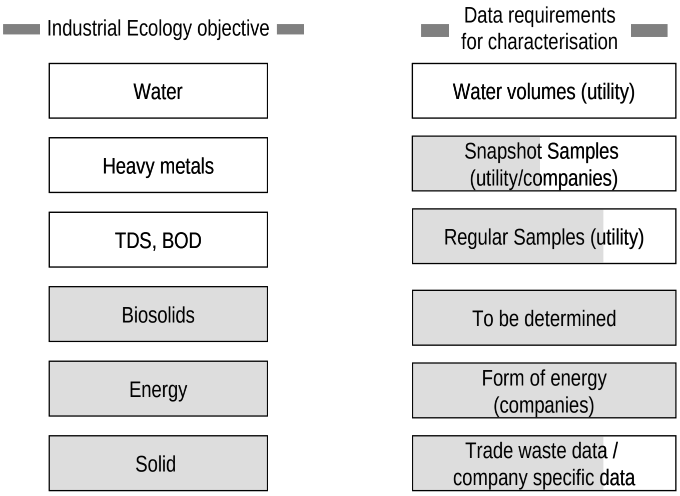
The availability of Melbourne-specific data will shape the direction of the project to the extent that required data not available can be sourced within the time frame of the project or whether less data-intensive approaches are required to be used. This interaction between the scope of the project, required tools and technologies and the data availability is illustrated in Figure 6-1.

Figure 6-1: Role of data availability on scope of project



The interaction between data availability and specific objectives for this project is illustrated in Figure 6-2. The grey areas show objectives which are less a focus of the project and for the data requirements the degree of grey represents the level of difficulty associated with obtaining good data. Whilst richer data sets may be potentially available from companies, it is expected that within the scope of the project these will be difficult to source, however some data may be available for specific case studies.

Figure 6-2: Relationship between data and objectives



Additionally, information is required on the location of resources and sinks, the treatment technologies which may be required and the costs of realising the synergy.

6.3 CRITERIA FOR SELECTION OF OPTIONS

The methodology proposed in the WSAA Sustainability Framework (Lundie et al. 2005) is similar to that used in other studies (eg. Chapple and Sullivan 1994; eg. Schroter and Ostrowski 2006), and consists of the following steps to be followed by representatives from across the group of project stakeholders:

- Step 1: Define problem and objectives;
- Step 2: Brainstorm scenarios;
- Step 3: Determine sustainability assessment method and criteria;
- Step 4: Screen scenarios;
- Step 5: Perform detailed impact assessment of selected scenarios, using LCA etc.;
- Step 6: Identify preferred scenario using multi-criteria decision aid (methods reviewed in Karrman et al. 2005).

Many sustainability assessment frameworks employ decision support software to evaluate different options along an agreed set of criteria. One example of this is the Swedish Urban Water Management program (Hellstrom et al. 2000). Similar methods have been used for engineering studies (eg. Warhurst and Mitchell 2000), in which data from simulation models informs decisions, eliminating the need for multi-criteria decision aids.

Input from stakeholders and the steering committee will inform which criteria are most important for selecting potential industrial ecology options.

6.4 PRELIMINARY ASSESSMENT OF CASE STUDIES: SPECIFIC INDUSTRIES OR INDUSTRIAL ZONES AND BARRIERS TO IMPLEMENTATION.

To be developed with input from stakeholders and at this stage there is interest and support for exploring an Altona case study further.

7 KEY FINDINGS

This section brings together the different elements of the literature review. The structure of this literature review is such that each sections answers specific questions that enable a greater understanding of the project to informs its future direction:

- What the project aims to achieve? (Section 1)
- Where is this situated in the field of Industrial Ecology? (Section 2)
- What tools and available for analysis? (Section 3)
- What technologies could be used to cycle resources? (Section 4)
- What can we learn from examples overseas? (Section 5)
- What regulations are in place that support or constrain the project? (Section 6)
- What are the drivers for this project? (Section 6)
- Have any initiatives already taken place in the region? (Section 6)

▶ What the project aims to achieve?

The aim of this project is to identify and undertake a preliminary assessment of one or more specific opportunities for industrial ecology in the Melbourne region that can be implemented in the short to medium term. Additionally, it is envisaged that the methodology developed will find wider applicability beyond the identified case studies.

▶ Where is this situated in the field of Industrial Ecology?

The type of opportunities that will be sought will involve the recycling of material between the manufacturing processes of two or more businesses or industry sectors. This project is therefore operationalising the principles of industrial ecology at the business and possibly sectoral levels. It is possible that during the course of research broader synergies at the supply chain level will be identified, in which these will be marked as areas for further research in the final report.

▶ What tools are available for analysis?

Input-Output analysis can be conducted at a sectoral scale to provide an estimate of potential synergies between sectors, based on average industry data.

The Input – Output tool developed by the CSRP could be used at a plant scale with sufficient company data to identify synergies in an industrial complex. Dynamic models could also be developed to consider possible savings arising from optimisation of flows between companies.

▶ What can we learn from examples overseas?

Many overseas examples of industrial ecology have taken place within Eco-Industrial Parks, and examples were reviewed in Denmark, the Netherlands, the US, China and Australia. These studies recognised that project that begun with small utility sharing projects between businesses often manifest into much larger recycling and reuse schemes that develop over decades. This type of development was shown in contrast to localised waste exchanges with limited scope and high capital costs, which were less sustainable over the long term.

Trust and relationships between companies are important elements of successful synergy projects, this is also reflected in the balance of synergies which have been pursued in Australian regions including Kwinana and Gladstone.

In China, a rapidly industrialising economy has led to the development of a Circular Economy, which is being taken on board at the highest level in development policy. Planning and constructing business clusters around sugar mills to use many of the waste products is one of the many innovative approaches that are emerging from this operating environment, however this approach is more aligned with new rather than existing developments.

▶ What regulations are in place that support or constrain the project?

At the national level, the National Water Initiative integrates the principles of industrial ecology at clause 66. calling for a review of pricing policies for trade waste that encourage the most cost effective methods to emerge. In Victoria, the Our Water Our Future white paper described a particular approach to the management of trade waste that pursues more opportunities for water and biosolids recycling. Action 5.31 of the white paper calls for a review of Victoria's trade waste management framework to incorporate increased recycling. Whilst supporting industrial ecology project indirectly, cost elements for individual projects will still need to be assessed.

▶ What are the drivers for this project?

There are a number of factors that mutually reinforce the current interest in industrial ecology in Melbourne. Economic factors such as rising utility prices are putting pressure on industry to be more efficient with the use of water and energy.

The scarcity of water in the urban environment has led to increased interest in recycling wastewater, and a particular focus on the Werribee wastewater treatment farm. This water however often has high salinity levels that render it not useable to industry and residential customers. Environmentally, reducing pollutant loads for discharge into Port Phillip Bay is a major cause of concern for industry.

The regulatory environment in Victoria and Melbourne is also changing, and the recently conducted Trade Waste Review has recommendations that will potentially tighten the controls on what industry can discharge to the environment. Some of the recommendations from the review may result in increased costs for pollution discharge or lower limits on the concentration of certain industrial contaminants such as cadmium and mercury.

▶ What initiatives have already taken place?

The sustainability covenants and cleaner production initiatives undertaken in Melbourne to date have established a generally positive relationship between business and industry which provides a sound basis for developing industrial ecology initiatives. Initiatives which are directed at reducing salt loads in Werribee are also planned.

▶ Summary

In conclusion, this literature review demonstrates that the principles of industrial ecology have been successfully applied to identify synergies overseas and in Australia (notably at Kwinana). Input-output tools with varying data requirements are available to identify opportunities. The objectives for the project will inform data requirements. It is expected that limited company data sets may be available. The next steps are to gather information from stakeholders at a workshop regarding data, drivers and the approach to be taken in the remainder of the project in light of the findings of this review.

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9 LIST OF STAKEHOLDERS AND EXPERTS CONTACTED

Name	**Organisation**	**Area**
Dr Peter Holt	Ecological Engineering, Melbourne	Wastewater treatment technologies
Dr Martin Treitz	Institute for Industrial Production, Germany	Optimisation of production processes (with China, Chile case studies)
Örjan Lundberg	Chalmers University, Sweden	Eco-industrial parks
Prof Markus Reuter	University of Melbourne	Ind. Ecology in Europe
Prof Stuart White	Institute for Sustainable Futures	Salt reduction strategies
A/Prof Bo Jin	University of South Australia	Wastewater treatment technologies
Prof Felicity Roddick	RMIT University	Water quality
Nigel Corby	City West Water	Company involvement in water saving initiatives
Brod Street	DSE	Trade waste & policy
Andrew Fennessy	DSE	Trade waste & policy
John Lind	DSE	Trade waste & policy
Peter Donlon	WSAA	Salt reduction initiatives
Carmel Vlahos	EPA Victoria	Trade waste & policy
Michael Anderson	EPA Victoria	Trade waste & policy
Luke Barker	EPA Victoria	Trade waste & policy
Melissa Stewart	EPA Victoria	Trade waste & policy
Robina Westblade	EPA Victoria	Trade waste & policy
Mark Fitzgibbons	ESC	Price and trade waste
Cheryl Batagol	Chair, Melbourne Water	Case Study Altona
James Macdonald	PACIA	Industry Association
Andrew Brown	Australian Vinyls	Pilot Industrial Water Recycling in Altona