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QUALITATIVE DECENTRALISED SYSTEM CONCEPTS

VOL 1: SYNTHESIS REPORT FOR MELBOURNE WATER

UNIVERSITY OF TECHNOLOGY SYDNEY

Institute for Sustainable Futures

DEVELOPMENT OF QUALITATIVE DECENTRALISED SYSTEM CONCEPTS

FOR THE 2009 METROPOLITAN SEWERAGE STRATEGY

Volume 1 - Synthesis Report

For Melbourne Water

Authors

Cynthia Mitchell, Kumi Abeysuriya and Dena Fam

Institute for Sustainable Futures

Disclaimer

Acknowledgements

This project applied an innovative, highly collaborative methodology to address the very broad scope and very tight timeline required by the Melbourne water authorities. We invited members of our local, national and international network to join this highly strategic project, and share their current and future projects and visions for sustainable urban sewage systems.

We gratefully acknowledge the wonderful contributions from these individuals, named below.

ISF and UTS	External
Carlia Cooper	Tracy Adams, Biolytix, Australia
Monique Retamal	Cori L. Barraclough, Aquatex Scientific, Canada
Dana Cordell	Assoc. Prof Jan-Olof Drangert, Linkoping University, Sweden
Dr Damien Giurco	Prof Tony Fane, UNSW Australia
Dr Chris Riedy	Dr Therese Flapper, Alchemy, Australia
John McKibbin	Carol Howe, UNESCO-IHE, SWITCH, Netherlands
Dr Simon Fane	Prof Petter Jensen, Norwegian University of Life Sciences, Norway
Chris Davis (UTS)	Craig Lindell, Aquapoint, USA
	Patrick Lucey, Aquatex Scientific, Canada
	Steve Moddemeyer, CollinsWoerman, USA
	Prof Greg Morrison, Chalmers University, Sweden
	Dr Valerie Nelson, Coalition for Alternative Wastewater Treatment, USA
	Dr Korneel Rabaey, University of Queensland, Australia
	Aaron Spicer, Lend Lease Ventures, Australia
	Jerry Stonebridge, President, NOWRA, USA

Executive Summary

Melbourne Water, in collaboration with City West Water, South East Water and Yarra Valley Water, are developing the 2009 Metropolitan Sewerage Strategy for the provision of sustainable sewerage services to Melbourne over the next fifty years.

The Institute for Sustainable Futures wishes to congratulate the Melbourne water authorities for their legacy-based, future oriented approach, and intention to align long-term and short-term actions to deliver the best mix of centralised and decentralised system responses to uncertain challenges, whilst minimising impacts in economic, social, and ecological terms.

This report is an interim output. It has been prepared as input to an Expert Workshop. The goal of this report is to bring together qualitative decentralised concepts that will meet the long term goal of a robust, flexible, sustainable sewage system. Following the workshop, in a separate project, preferred concepts will be developed to engineering concept design stage.

Our focus in this work was to identify and synthesise the principles and practices (both technological and institutional) that will be necessary to deal with a complete rethinking of sewage, from viewing it as a waste, to viewing it as a resource. The scope was broad and included every element of the system, from upstream to residuals management; every source type; every density type; and every development type.

We engaged an extensive local, national, and international network encompassing more than 20 experts at the leading edge of technology, development and practice globally to generate the concepts and case studies detailed in this report.

In the process of comparing and contrasting the Strategy's principles with the concepts and case studies, we identified four key long term challenges for sewage in Melbourne:

> Environment: what would it take to design out environmental impacts from sewage?
>
> Systems: what would it take to design a sewage system that creates no waste?
>
> Community: what would it take to match engagement processes with questions, such as representative, deliberative processes for big infrastructure decisions?
>
> Value: what would it take to implement sustainability accounting for the authorities and all their service providers?

We also identified eight key lessons and recommendations:

- Undertake pilot and demonstration projects
- Generate trust
- Collaborate with regulatory authorities
- Maximise value from existing assets
- Recognise interactivity between technology and behaviour
- Pay attention to residuals
- Apply the n-R's principle system-wide
- Balance short term and long term actions

Volume 1 (this document) is the synthesis report. It contains an analysis of all 40 or so concepts and case studies, and integrates these with the outcomes of teleconference workshops and other sources, to align the ideas with development typologies. Volumes 2, 3, and 4 contain the detailed resources.

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1 Context

Melbourne Water, in collaboration with City West Water, South East Water and Yarra Valley Water, are developing the 2009 Metropolitan Sewerage Strategy for the provision of sustainable sewerage services to Melbourne over the next fifty years.

The Institute wishes to congratulate the Melbourne water authorities for their legacy-based, future oriented approach, and intention to align long-term and short-term actions to deliver the best mix of centralised and decentralised system responses to uncertain challenges, whilst minimising impacts in economic, social, and ecological terms.

Between now and 2060, conceptions of sewage will likely shift enormously, from how to manage it as a waste, to how to extract and reuse the resources it contains. These resources include water, carbon, and nutrients for residential and commercial sewage, and other constituents for industrial sewages. So, the sewage system needs to be considered in conjunction with other systems, including, as a minimum, the rest of the water system as well as the energy system eg energy recovery, the solid waste system eg co-digestion with organic solid waste, and the nutrient system eg recovery of phosphorus because of looming shortage, and nitrogen because of energy intensity associated with fertiliser production. There may be others.

As well as the shifts outlined above, the Strategy seeks to accommodate the uncertainties with respect to the critical sewerage planning dimensions of the nature of urban growth, population growth, climate change and living standards over the coming decades. As changes occur in technology, public values and the broader water cycle as well as in the critical planning dimensions, the Melbourne authorities have recognised that flexibility in the system will be key to successful service delivery in the long term, and that means finding the best mix of centralised and decentralised approaches.

This project is embedded within a series of projects related to the Strategy. Earlier work identified critical sewerage planning dimensions, and then used those to develop a set of scenarios to describe possible futures. A portfolio approach emerged as the best approach for dealing with uncertain futures. In this project, the focus is on qualitative concepts, configurations, and case studies of decentralised and on-site systems to service different urban development characteristics. This project assumes a future where adaptive, proactive responses are the norm. Ideas proposed here will be winnowed to a preferred set, which will be taken forward and developed into quantitative engineering design concepts in the next stage of the Strategy.

The Melbourne authorities have engaged four consultants to complete this project. Our role at the Institute for Sustainable Futures (ISF) is a little different from the others - our focus specifically includes is the long term, right out to 2060. That means our scope includes technologies and associated socio-economic processes that exist now, and/or that are currently proven and commercially available, as well as emerging technologies and processes, and strongly future oriented ideas.

This report is an interim deliverable. Each of the four consultants are preparing reports for, and participating in, an Expert Workshop. Following the workshop, a final version of this report will be prepared.

2 Project Overview

Goal and Scope

The project goal was to support the Melbourne Strategy prepare to develop the best mix of centralised and decentralised infrastructure responses to future scenarios, and specifically, to assemble a portfolio of decentralised concepts and case studies applicable to a range of development types.

The scope was to consider options with broad coverage, including:

- Development types – new, infill, retrofit developments; low, medium and high densities
- System elements – upstream, conveyance, treatment, productive re-use, residuals management
- Sewage types – residential, commercial, light industry and heavy industry sewage (non-regulatory, light regulatory and heavy regulatory),
- Anticipated performance status over time – now, in 2030 and 2060
- Linkages to other systems – water supply, stormwater, water cycle, energy, solid waste, nutrients, agriculture etc.

Methodology

Our methodology needed to respond to the very broad scope of this project and the very short timeframe for its completion. We therefore sought to engage with the global leading edge of the decentralised (on-site and cluster) industry, as well as with the relevant elements of industrial ecology and technology foresighting. Our approach relied on our existing deep knowledge and experience in these three realms, and our extensive national and international peer network of practice-based, big thinking experts in these three realms. In each realm, we targeted practitioners, developers, and researchers in Australasia, North America, and Europe. We bolstered the inputs of external experts with a scan of web-based literature and case studies. We captured the outcomes of these processes in three ways. Firstly, through templates designed to facilitate reflective responses to key questions, including purpose, description, schematic, and management implications. Secondly, through leveraging information technology, we identified and used a web-based mechanism for creating a virtual community for our expanded team of experts. This site acted as a repository, and also as a communications tool within the expert group. Thirdly, we held two international structured teleconference workshops - one each to match European and North American timezones. Australian participants joined the timezone that suited them. Because a collaborative approach is key to the success of high intensity project, access to the website and teleconferences was extended to representatives of the Melbourne authorities.

This expert-based approach is a new model, and one that worked extremely well in this project. It allowed an additional outcome that we did not envisage - we have been creating community at the leading edge. We knew this group would see the enormous strategic value in the project, and because of their various passions, would likely seek to make space in their busy schedules to contribute. We wanted to reciprocate, and clearly acknowledge the value of the experts' knowledge and experience, so we offered each of them a small honorarium. In addition, we wanted to give them something we knew they would value even more - access to the pooled resources, and we achieved that through the web technology we employed and the teleconference workshops. Finally, we surmised that if we could facilitate a conversation between these people, even more great ideas would emerge, and that certainly occurred through the teleconferences. What we did not envisage is the impact this project has had in creating community across this group at the leading edge, which augers well for future long-range thinking in sewage systems, and in particular for Melbourne, because this group of leaders now knows and can promote Melbourne's strategic long term approach.

Introduction to this report

Our methodology yielded a wide range of inputs from our various collaborators and ISF team across a wide range of dimensions. To capture these in a navigable manner, we present this report in four volumes.

Volume 1, this document, seeks to synthesise the wide-ranging inputs – contributions of concepts and case studies, ideas and comments shared through the teleconferences and web space and literature – and to make some recommendations for the next steps for the Melbourne Sewerage Strategy.

Thus, it begins with an overview of principles and process that emerged through our collaboration, that resonate with, complement and extend the Strategy's guiding sustainability principles and highlights critical process issues to be mindful of in the process. Secondly, it steps through a synthesis of the concepts and case studies by relevance for particular development types and sources i.e. city wide, existing, new, and industry. Thirdly, it provides an overview of the case studies and virtual case studies. Finally, it highlights key lessons for Melbourne.

Volume 2 is a portfolio of concepts, case studies and virtual case studies, each presented in the template format.

Volumes 3 and 4 are indexed sets of resources contributed by our collaborators as key literature. Volume 3 is devoted to Integrated Resource Management resources, and Volume 4 brings together other papers, reports and links.

3 Principles

The goal of Melbourne’s Sewerage Strategy is to provide sustainable sewerage services into the future. The Strategy recognises that planning for this needs to take account of uncertainties in critical sewerage planning dimensions– in particular, the nature of urban growth, population growth, climate change and living standards over coming decades.

To achieve this goal requires big shifts from the way sewerage is currently perceived, designed, planned and implemented. This means both shifts in technology and in social processes (i.e. regulatory, institutional, and financial arrangements to shift behaviours of all players, from water authorities to consumers).

The Strategy has defined a vision and a set of principles against which potential new directions could be assessed for sustainability. Several resonant and complementary ideas were canvassed in the course of our engagement with our external collaborators, which we draw together with the Strategy’s principles and some of ISF’s work. The synthesis shows that the Strategy’s principles are appropriately broad, and that there is potential to further strengthen them in terms of their capacity to deliver truly sustainable sanitation. The result is a rich set of principles which will be terrifically valuable as the benchmark for Melbourne’s water authorities to hold themselves to, as they take forward their long term planning and transitional arrangements.

The Strategy’s Principles are reproduced as italicised bullet points below. We have summarised complementary ideas to each Principle (or group of Principles). Naturally, there is overlap between the ideas below. For clarity, we have sought to locate complementary ideas at the strongest points of intersection, rather than to note all the possible linkages.

Environment

- *The natural environment, including its biodiversity, will be at least protected from further degradation, if not improved and enhanced. All our activities will be undertaken with a minimal ecological impact.*

The distinction between ‘sustainable’ and ‘restorative’ future developments of the sewerage system is useful here. The objective to protect the natural environment from further degradation seeks to go beyond best practice to achieve a ‘sustainable’ target of no net adverse ecological and social impacts. To attempt to improve or enhance the environment is the stretch objective to be ‘restorative’ and have net positive social and ecological impact as a result of future sewerage developments. Restorative practices are necessary because some areas will not reach the sustainable goal, and because remediation is required for existing and historical impacts.

Practices aligned with this principle include restoring predevelopment hydrological systems -- restoring streamflows and habitat, and recreating natural cycles of groundwater infiltration and evaporation. The primary design criteria for all aspects of the future system would be to use the least amount of natural resources, disrupt the least number of natural cycles that occur on the site and in the area, and use the least amount of energy at final build-out.

'Sustainable' objectives are exemplified by InterfaceFLOR. Over the last 15 or so years, InterfaceFLOR have done the impossible - shifted their business from a petroleum-dependent, highly polluting once-through operation to a restorative business model that seeks to mimic nature by designing cyclic material flows; to eliminate waste by complete recycling of old products into new products; to ensure emissions from manufacturing processes are benign; and to use renewable energy. That is, they did a total re-design of every element of their operation, step-by-step, making significant savings that were re-invested in new processes, resulting in rapid growth of the organization. The concept of design as the key leverage mechanism for getting value out of assets is exemplified by Interface, and kept rising up in the case studies and discussions through this project.

The challenge for Melbourne is what would it take to design out environmental impacts from sewage?

Systems

- *Strategic planning outcomes and associated activities and investment programs will acknowledge the interconnection of the various aspects of the water cycle and how they impact on each other.*
- *We will view sewage as a resource and aim to protect and conserve Victoria's water resources and use resources efficiently.*

These convey the idea of interconnection between various elements of a complex system of water and other material flows, for which there are several complementary principles about taking a systems approach to managing resources efficiently and effectively. The key is to design in interlinkages between sewage and water, energy, solid waste, nutrient and other systems.

Integrated Resource Management, the first concept on our list, is an exemplar of this approach, which can have many permutations and configurations, including industrial symbiosis. It is a commitment to use solid and liquid waste to create energy, reduce greenhouse gas emissions, conserve water, and recover nutrients that requires a conceptual total resource recovery design within an ecological engineered framework.

The key companion concept here is a value-based approach, rather than a cost-based approach - that is, framing the question as what would it take to create the most value from this resource, rather than how do we minimise the cost of treating this waste?

With the advent of new technologies (e.g., nanotechnology) it is conceivable that in the near future it would be possible to run sewage effluent through a resource recovery wafer that will capture all the chemical elements and allow the water to pass through for reuse.

In our teleconferences, Craig Lindell talked about a 'network centric' approach - one that responds to the complexity of the interconnected system by appreciating the particular context that informs the technologies, the skills, the processes and the organisations that enable it to be managed most effectively. This approach seeks to 'design with nature' in the particular context, utilising natural systems as integral elements of the infrastructures. The underlying principle is to build an adaptive interface between human communities and natural systems to achieve a system-wide sustainable hydrology. This becomes possible through "community-wide collaboration, expansive creative thinking and rigorous critical reasoning".

The challenge for Melbourne is what would it take to design a sewage system that creates no waste?

Community

- *Our actions will contribute to the health of the community.*
- *We will engage the community and stakeholders in a collaborative manner to achieve better decisions.*
- *Intergenerational equity will be maintained through considering long term as well as short to medium term implications in all decision making.*

We see a range of principles here, from the advocacy role water authorities could take in encouraging an extended producer responsibility framework for problematic sewage contaminants, through waste reduction principles, to deliberative engagement about large and small infrastructure decisions.

A key challenge facing society now is the ever-expanding list of manufactured products from our industrial society that end up in sewage, rendering it uneconomic to treat and preventing its beneficial reuse. There is an example of a strategic framework in another sector that might, perhaps should, be applied and adapted to sewage, and that is the idea of extended producer responsibility (EPR). As Dana Cordell and Jan-Olof Drangert noted, an EPR framework would address the pending responsibility of the chemical and pharmaceutical industries to better control the products they manufacture and sell. They suggest a study of this area would need to be solution-focused, use case study contaminants, identify problems and also technical and regulatory solutions including the relative costs and benefits of such solutions. It would consider the potential role of the chemical and pharmaceutical industries in particular, to manage critical contaminants including loads, pathways, roles and responsibilities, barriers and opportunities.

These principles also link to promoting the 'reduce, re-use, recycle' hierarchy across society. Therese Flapper urges us to adopt this hierarchy in a much more coherent way than we have to date. There are several complementary variants of the 3 R's concept that disaggregate the functions implicit in the 3 R's as well as add further elements, for sustainable water management from ecological and social perspectives. For example, Valerie Nelson's 12 R's include additional verbs such as 'Reclaim', 'Retain' (rainwater for infiltration), 'Recover' (energy and nutrients), 'Restore' (hydrological flows), and 'Regenerate' (neighbourhoods), 'Recover' (stable green-collar jobs), and 'Remove' (trace contaminants and micro pollutants) and so on.

Matching the type of engagement to the decision type is essential. Around the world, a new engagement process is catching on across civil society for making better decisions. The processes have different names, but they have in common two key characteristics: representative and deliberative. The former means the participants are randomly selected and actually represent the society of concern, rather than a noisy or powerful minority. The latter means that the outcomes of the process will impact on the decisions of authorities. Contrary to the expectations of some experts, these processes deliver well-informed, fair, and equitable decisions (Fung and Wright

2003). In the sewage sector, these processes could provide much-needed public backing for new approaches to infrastructure and institutional arrangements.

The challenge for Melbourne here is to match the engagement process with the question: big decisions should have stronger engagement processes.

Value

- *We will establish affordability and customers' preparedness to pay for the options being considered and include this information in the decision making process.*
- *The financial viability of the water businesses will be maintained over the long-term.*
- *Decisions will be based on best available science and information, and on least community cost assessed on a triple bottom line basis.*
- *We will embrace innovation and show leadership in the pursuit of sustainable outcomes.*

The provision of water and sewage services to all at the lowest societal cost underpins a well-functioning society. However, assessing societal cost, i.e. costs from different perspectives, over the life cycle of a piece of infrastructure is a complex activity, particularly when seeking to compare supply and demand side options, or centralised and decentralised options. Adopting costing processes and systems to ensure equitable analysis underpins decision making is key (see, for example, the guidebook prepared collaboratively with Melbourne and other authorities (Mitchell et al., 2007.))

A radical shift that aligns sustainability with decisions that make economic sense (financially viable and affordable) can be achieved by moving from 'cost based' evaluation to 'value based' evaluation. 'Cost based' valuation seek outcomes at *least cost* and has been the dominant paradigm for infrastructure selection and design. 'Value based' approaches, in contrast, seek to design systems to yield the *most value*. Such a shift in perspective has the potential to radically change what infrastructure decisions are made. It also aligns with global shifts in valuation practices (for example, the Vancouver Valuation Accord) which seeks to bring in 'green' values, and begins to open up opportunities for capturing increases in value associated with new infrastructure provision.

What is also certain is that the business structure of sewage service provision will change markedly in the next decade, and on into the next half-century. Appropriate roles and responsibilities are yet to be configured. Here too, demonstrations will be essential.

The challenge for Melbourne is what would it take to implement sustainability accounting for the authorities and all their service providers?

4 Matching Concepts and Case Studies to Development Types

The resources we collected are called concepts or case studies, and in reality, they are not so easily defined as one or the other. Instead, they occupy a spectrum - some are definitely conceptual, some are physical concepts, some are case studies that embody and demonstrate other important concepts, and some are just great case studies. Each applies over a narrower or wider spectrum of development types and densities, and sources. In this section, we identify and integrate the ideas from this perspective of applicability, in order to ease the integration of this work with the engineering concept design stage that follows.

Most concepts and case studies have broad applicability, and the dimensions of this study are cross-cutting, for example, new and existing installations can refer to any source (non-regulated residential/commercial, light regulated industry, heavy regulated industry) and to any density (activity centre, high, medium or low). Equally, there is overlap between sources and density, in that different sources can occur at different densities.

We have sought to provide some specificity and avoid duplication in this section by exploring concepts and case studies in detail just once - at the strongest point of their applicability in the following typology.

1. city-wide;
2. retrofits of existing residential or commercial (range of densities);
3. new residential or commercial (green or brown field sites) (range of densities, including activity centres); and
4. industry.

We provide pointers to their other applications when they are discussed in detail.

The concepts and case studies are referenced with respect to Volume 2 of this report - C9 is Concept 9, and CS4 is Case Study 4, etc, in that volume. The complete list of concepts and case studies is included in Tables 1 and 2 on pages 29 and 33.

City Wide

> *'In the 20th century, management was the primary mechanism for leveraging assets. In the 21st century, it will be done through design.'*
>
> *Craig Lindell, Aquapoint, Project Teleconference, 08 October 2008.*
>
> *'And it will be done through engineered ecology - that is designing with nature.'*
>
> *Patrick Lucey, Aquatex Scientific, Project Teleconference, 08 October 2008*.

Perhaps not surprisingly, the concepts and case studies that operate city wide tend to be higher level principles. They include:

C1 Resources from Waste - Integrated Resource Management (IRM) C2 The 12 R's of Sustainable Water Management C5 Biosolids and Sustainability: The Natural Step 2020 Visioning Project C6 Run to Failure C7 Reactors at Interceptors	C8 Removing micropollutants C10 Enhanced Role of Private Sector C12 3Rs: Reduce, Reuse Recycle C13 Urine diversion and reuse C14 Decentralised Water Infrastructure - the 21st Century Paradigm C15 Distributed sewage network
CS2 Sewer heat recovery CS8 King County Inflow/Infiltration	CS10 Low Impact Development Toolkit CS15 Urine separation pilot SWITCH

The run to failure idea (C6) is perhaps the most significant principle amongst these, because it provides a pointer as to where it might make sense to invest in decentralised systems. In it, Valerie Nelson from the USA argues that instead of pumping large sums into repairing ageing and failing infrastructure, we should pivot those investments into the new approaches. She asks what opportunities for innovation and demonstrations would open up if we decided to decrease our reliance on centralised systems, for example, if we decided that there would be no more capacity enhancements or repairs in traditional modes. Significant questions emerge, alongside the need to accept responsibility for demonstrations as a core part of the transition.

A city-wide focus on urine diversion is seen as an increasingly certain[1] part of a sustainable future (C13, CS15). Urine contains most of the nutrients excreted in sewage (up to 80% of nitrogen, around 50% phosphorus and 70% potassium). Removing these from sewage has the potential to drastically reduce treatment energy and costs as well as environmental impacts. At the same time, it recovers valuable nutrients in useful ratios, which leads to even further benefits when urine replaces artificial fertilisers, and the production of nitrogen fertilisers is extremely energy intensive. At present in Europe, the only treatment of urine prior to reuse is storage to allow for die-off of microorganisms. Two municipalities in Sweden have mandated that all new developments should have urine diversion toilets, driven by environmental protection concerns as well as national targets for nutrient recycling to

[1] At the On-Site and Decentralised Sewerage and Recycling Conference in Benalla on 15 October 2008, Professor Emeritus George Tchobanoglous predicted that urine would be a commodity within 5 years.

agriculture[2]. There are several manufacturers of urine diverting toilets in Europe, and in Australia, Caroma is working on prototypes. A significant driver is rapidly diminishing global rock phosphate reserves and the implications for global food security because there can be no substitute. In Australia, there is just one small trial underway to date, at Currumbin Eco-Village, and there are still technical, regulatory, and reuse issues to be sorted. What is certain is that phosphorus recovery will significantly impact the entire sewage system (design and operation as well as regulatory and pricing structures) within the next couple of decades.

There is a further note-worthy side-benefit in the diversion of the urine stream away from the sewage stream: micropollutants (endocrine-disrupting chemicals, pharmaceutically active compounds, and personal care products) partition more strongly into urine than faeces when we excrete them. Keeping these components out of the dilute water-borne sewage stream again removes the need for additional energy-intensive tertiary treatment to remove them prior to water recycling. In a further useful side-note, recent work suggests that upper layers of the soil profile will provide significant sorption and breakdown of micropollutants (Asano et al 2007, Tchobanoglous 2008). Direct ground injection (similar to current approaches for applying urea) of urine as a fertiliser could be a very sound answer to the problem of how to deal with these compounds.

The issue of micropollutants and their removal (C8) is another city-wide concept with implications significantly beyond the water authorities. According to Assoc Prof Jan-Olof Drangert, and we agree with him, it is the current incarnation of an historical problem: treatment and reuse systems are at the mercy of changing consumer products in society. The underlying cause behind successive breakdowns of efficient urban systems for collecting and reusing nutrients a century apart is the addition of new products to the waste stream that render it useless. A hundred years ago it was bottles and cans, now it is chemicals and heavy metals. The solution lies in reducing the problem at source, which requires far stronger legislation for producers, and shifting responsibilities for proving the efficacy of treatment and removal of products.

A distributed sewage network (C15) is another significant idea that explicates Craig Lindell's notion of 'network-centric' approaches. The bigger idea of network-centric approaches comes from naval intelligence. The idea in the distributed sewage network is that redundancy in distributed systems is provided through a network of cluster scale treatment systems, rather than 'fail to sewer', because the latter doubles up on infrastructure, resources, and costs, largely unnecessarily. This also links to C20, the concept of recycled water grids, discussed elsewhere because it is more a high density, activity centre concept.

The 12Rs (C2) and the 3Rs (C12) are all about the principles that should inform sustainable water management. The 12Rs is a comprehensive list, covering efficient and effective resource use as well as sound business and regulatory models and green collar job creation. The 3Rs seeks to emulate the success of the solid waste recycling revolution in the water sector. It recognises that demand management programs have been successful, and that there is still plenty of opportunity to improve the efficiency (i.e. volume per unit service) and effectiveness (i.e. fit for purpose) of our water systems, and that decentralised systems have an enormous role to play in making this real at the community level.

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2 Sweden is a leader in the use of life cycle assessment to guide globally leading national policies. For example, in 1996, the Swedish EPA were funding a significant study on food miles in Sweden, way before the term had even entered the lexicon elsewhere. One result was a national target for the return of nutrients to agriculture, to encourage local productivity at reduced ecological footprints.

The 21st century paradigm (C14) is a comprehensive explication of a new approach to water systems, outlining the drivers, the benefits, the principles for how it might be achieved, including biomimicry, the business opportunities, and the market transformations required. The key principle here is to keep everything local, as much as practicable: water-centric subdivisions moving toward 'off-the-grid' efficiencies and maintaining local hydrological cycles - a kind of sustainably-supercharged version of water sensitive urban design.

Enhancing the role of the private sector (C10) reflects the wide range of opportunities for private sector involvement in the broad range of service contract arrangements made possible by decentralised systems. In the US, this landscape is a little more developed than here, particularly for decentralised sewage, with the concept of 'responsible management entities' spanning contract maintenance through to small-scale systems located on home-owners' property but owned and operated by another entity. There is some debate about who is best placed to play these roles - this template argues that private providers are preferable because of the incentives associated with competition, and because customers are familiar and comfortable with the concept of choosing their own service people. The implication of this idea for Melbourne is a shift in the role of the water authorities, to one of oversight of a wide range of potential business models and providers. This links to the mechanisms in place in a Swedish municipality that has mandated urine-diverting toilets in all new developments (see C13). There, the municipality, who has responsibility for water and wastewater services, retains the bottom-line responsibility for removal of urine from storage tanks if something goes wrong in the contractual arrangements for this between a resident and a registered farmer.

IRM units (C1) are being planned for retrofitting in the city of Greater Victoria, the capital of the Canadian province of British Columbia. This approach seeks to link sewage and solid organic waste processing to maximise the recovery of resources, so it links to the water cycle through provision of recycled water, the energy cycle through both carbon capture and heat recovery, and the nutrient cycle through agricultural soil amendments. A key principle expounded by the proponents in this State-endorsed study is that the model is value-based, rather than cost-based, so the financial modelling shows significant savings in comparison to centralised treatment. The precise location of IRM units needs to be determined through balancing supply of resources for processing, and demand for products.

Reactors at interceptors (C7) is a new take on sewer mining - the primary driver is environmental protection rather than supplying recycled non-potable water. What Craig Lindell describes is two different business / regulatory approaches to use existing infrastructure to identify appropriate locations (interceptors) to extract and treat sewage - this approach reduces the costs associated with, in these cases, improving nutrient loading to estuarine ecosystems.

Sewer heat recovery (CS2) uses a case study of Vancouver to explicate how low grade heat has been effectively recovered for heating and cooling purposes in many locations globally. The case study reports a 3:1 ratio i.e., sewage from 300 apartments provides 90% of the heating and cooling demands of 100 apartments. This concept has relevance for Melbourne, where the number of heating days (i.e. days when buildings require heat input to raise internal temperatures above ambient) is significant. The primary operational issue with the systems in operation now is biofilm growth because it reduces the effectiveness of heat transfer. It may be that the huge breakthroughs occurring now in microbial ecology and the implications for our understanding of biofilm processes will provide key insights to solve this issue in the near term. Of course, the drastic increases in water efficient appliances (see CS14 Hyper efficient homes for tomorrow) will have significant impact on the potential for sewer heat recovery. Another risk would be a shift to decentralised infrastructure which would again reduce sewer flows. Implementing sewer heat recovery in areas with high population density may allow its adaptation to such change.

The UK biosolids visioning project (C5) focused on identifying what needs to change with the system across the spectrum of sewage sources in order for biosolids to become a useful resource. This group of 23 experts identified seven challenges that need to be overcome:

- Change perception that 'waste' is not a valuable resource: eg through demonstrating beneficial reuse with non-food crops
- Eliminate dangerous substances at source: this links to C8 and Prof Drangert's comments, and speaks to the role of water authorities in creating change upstream in the sewage system
- Further investigation and monitoring of potential health issues: in particular, to clarify potential for transmission of micropollutants and pathogens
- Decreasing volume and inappropriate content entering sewerage system: refers to the need to mirror education programs that have successfully changed behaviours in similar topics
- Rationalisation of sewage and treatment infrastructure: recognises the value of decentralised systems situated close to product and source
- Diversify beneficial sludge products: such as domestic gardening, community products, building products, etc
- More sustainable regulation to drive cyclical resource use without net accumulation of waste. We would add that such legislation needs to go right back to the source, to challenge manufacturers to shift their processes to avoid the production of intransigent product and waste streams. There are already examples of this occurring in Germany.

Inflow and infiltration (I/I)drive peaks in sewage flows, and therefore are strong determinants of infrastructure size and cost. Experience from Washington State in the Pacific North West (CS8) shows the value of a program that keeps water out of the sewers - significant increases in community benefits, reductions in environmental impacts, and huge cost savings - in one case, US$150M in avoided costs[3]. In one county, modelling showed that more than 90% of I/I occurs on homeowners lots, so they focused on low impact replacement of these side sewers with flexible lines. The template reports on the value of including all the potential elements: manholes as well as trunk, lateral, and side sewers. Those counties that did all four reported around 80% reductions in I/I. One county that focused on manholes only achieved just 23% reduction in comparison. The implication for Melbourne is about using a strategic asset management approach to identify where and how to invest resources in upgrading existing systems, and managing the quality of new installations.

Again from Seattle, CS10 sets out a Low Impact Development Toolkit which is similar to the principles that underpin effective impervious area goals here in Australia, about recreating local hydrological cycles, and it goes further in that it begins to explicitly recreate local linkages with energy - evaporating one cubic metre of water soaks up nearly 700 kWh, a significant figure in heating and cooling cycles, and reducing urban heat island effects. This concept is explored a little more in the Frasers case study (CS 13).

[3] Steve Moddemeyer, Project Teleconference, 8 October 2008

Retrofits of existing residential or commercial

In the table below, we list all the concepts and case studies that have useful application for retrofitting existing residential or commercial sewage sources. The grey lettering denotes concepts and case studies already covered in detail.

C1 Resources From Waste (IRM)	C10 Enhanced Role of the Private Sector
C2 12 R's of Sustainable Water Management	C11 Nanotechnology
C5 Biosolids and Sustainability: The Natural Step 2020 Visioning Project	C12 3Rs - reduce, reuse, recycle
C6 Run to Failure	C13 Urine diversion and reuse
C7 Reactors At Interceptors	C14 The 21st Century Paradigm
C8 Removing micropollutants	C15 Distributed sewage network
	C20 Recycled water grid
CS2 Sewer Heat Recovery	CS12 Earth Power Technologies - food waste-to-energy facility
CS3 Energy neutral sewage treatment	CS14 Hyper Efficient Homes for Tomorrow
CS5 The zero emission university	CS15 Urine separation pilot SWITCH
CS6 Biogas as vehicle fuel	CS16 Biolytix
CS8 King County Inflow/Infiltration	
CS10 Low Impact Development Toolkit	

There are many technologies in the field of on-site and cluster sewage treatment. A handful stand out from the crowd because of the robustness of their design and the subsequent reliability of their performance. Biolytix is one of these, and we mention it here because it is a proven Australian invention. The Biolytix system is based on a vermiculture ecosystem: a biomimicry approach to design that means its ecological footprint is very low. It has been well-researched in successive developments over the years. More recent innovations (Cameron 2008) have focused on improving its transportability, leading to a new patented system for pressure-holding plastic seals without welds, and mesh telemetry to further increase the capacity for clever remote control processes. To date, Biolytix systems have been retrofitted to existing unsewered areas, and installed in new developments. In a run-to-failure scenario, they (or similar technology) could also be retrofitted to existing sewered areas on average suburban lots, providing benefits in energy consumption for sewage treatment, and local water recycling.

Recycled water grids (C20) offer a means of reducing the costs and environmental impacts associated with a ‘transmission’ view of recycling. In this scenario, applicable to high density areas of existing and new development, recycled water is recovered in several different local locations. The grid brings together multiple suppliers and customers, leading to a better match between supply and demand, with energy and resources invested in treatment rather than transport, and improved flexibility. It requires legislative oversight of the kind provided by the NSW Water Industry Competition Act (2008). Some grids may be able to make use of existing, disused infrastructure, such as gas lines under central business districts, or potentially redundant sewers in the future, etc, further increasing their efficacy.

Related to recycling water is the concept of recycling carbon - three case studies provide great examples of how to go about upgrading existing treatment systems to shift the processes and products towards more sustainable outcomes. The European TRENDSETTER project demonstrates biogas production (CS6) and use as a transport fuel. Energy neutral sewage treatment has been demonstrated in Strass (CS3) at a plant serving up to 200 000 EP. Related concepts for energy recovery from biosolids at treatment plants are under development and in operation in Brisbane. In Sydney, EarthPower (CS12) is Australia's first regional food waste-to-energy facility, accepting source-segregated waste from industrial, commercial, and domestic sectors as well as biosolids from sewage treatment plants. The products are biogas and pelletised nutrient rich fertiliser for agriculture.

Hyper-efficiency (C14) is here now e.g., very low flush toilets and very low volume recycling showers, and its rollout will increase dramatically in the coming decades e.g., waterless washing machines or clothes that do not require washing. The Melbourne water industry is very familiar with end-use modelling, and so familiar with the process of changes in the stocks of appliances in the community. Hyper-efficient appliances can and should be retrofitted into existing homes. Such appliances have implications for sewage conveyance, so one of the technologies outlined in this template describes a device for collecting domestic sewage at the household scale and batching its delivery to the sewer to assist in solids movement.

Related to this retrofitting idea is the commitment by the Norwegian University of Life Sciences to become a zero emissions university (CS5). About 10 years ago, the university agreed to using a new student apartment block as a demonstration unit, where vacuum toilets were installed, along with a greywater treatment system. In a collaborative project between the ecological engineers and the agricultural engineers, the blackwater was co-digested with animal waste, and the resulting liquid fertiliser directly ground-injected into broad-acre crops. The university has now committed to a gradual transformation of all its building stock to a similar process, as well as providing additional capacity to receive blackwater from surrounding residents. This project has two dimensions worth highlighting - firstly, the importance of demonstration projects to learn from experience, and secondly, the role of public institutions in taking a leading stance. Melbourne already has a history of the latter, with CH2 and other green building projects. The opportunity is to encourage more affordable examples to drive change for the majority.

Nanotechnology is set to be the driver of 'Industrial Revolution II'. Template C11 describes just three examples of nanotechnology products relating to sewage treatment. We discuss nanotechnology here because these breakthroughs will provide new options for retrofitting decentralised treatment systems into existing structures, for both residential and industrial settings. Such systems are likely to have quite small footprints, because the specificity of treatment processes reduces the number of unit operations required and greatly increases efficiencies. The big unanswered question with nanotechnology is about the risks associated with nanoparticles 'escaping' into the environment, so this is probably still a medium term concept.

New residential or commercial (green or brown field sites)

In the table below, we list all the concepts and case studies that have useful application for new residential or commercial sewage sources. The grey lettering denotes concepts and case studies already covered in detail.

C1 Resources From Waste (IRM)	C12 3Rs - reduce, reuse, recycle
C2 12 R's of Sustainable Water Management	C13 Urine diversion and reuse
C3 Agro-housing	C14 The 21st Century Paradigm
C7 Reactors At Interceptors	C15 Distributed wastewater network
C8 Removing micropollutants	C19 Decentralised Sanitation and Reuse (DESAR)
C10 Enhanced Role of the Private Sector	C20 Recycled water grid
C11 Nanotechnology	
CS2 Sewer Heat Recovery	CS10 Low Impact Development Toolkit
CS3 Energy neutral sewage treatment	CS11 Rocky Springs
CS4 Gothenburg Biowaste	CS13 Frasers Broadway
CS5 The zero emission university	CS14 Hyper Efficient Homes for Tomorrow
CS6 Biogas as vehicle fuel	CS15 Urine separation pilot SWITCH
CS7 Hammarby Sjostad	CS16 Biolytix
CS9 Flintenbreite Lubeck	

Rocky Springs (CS11) represents the leading edge approach to new suburban developments in Australia. In this case study of a new regional town centre for around 35 000 people, developing over the next 25 years, the developer has recognised the potential for a win-win situation with decentralised sewage management. They reduce their up-front costs and match infrastructure roll-out to real demand, and the community gets a more sustainable sewage system (i.e., lower energy footprint, lower nutrient releases, local public open space irrigation, etc). The key point here that cannot be overemphasised is the extraordinary lead time in these situations. Decisions made now, in the planning stages for this development, set in stone the infrastructure for the life of the development - not just through the roll-out, but forever more. These are exactly the opportunities that the industry has to grab with both hands and approach as demonstration projects, in order to work through the inevitable technical, managerial, and financial issues associated with doing things differently.

All the other concepts and case studies highlighted here, like the IRM concept (C1), take a systemic approach to sewage management. Firstly, source separation is paramount, in order that the ‘rate of return’ is maximised i.e. that resources are recovered for the lowest possible investment of energy and resources. Secondly, they explicit seek to connect the sewage system with as many other systems as possible - water reduction and recovery, recovery and reuse of organic solid wastes e.g., through co-digestion, and nutrient recovery and reuse e.g., through urine diversion or through sludge recovery. The examples come from all over the globe - a downtown development in Sydney (CS13), a new concept in China (C3) to lessen the cultural implications of the rapid shift from rural to urban life, a concept from German research and development leaders for both developed and developing world scenarios (C19), a development in Stockholm that started as an Olympic village

(CS7), and one of the world's best known eco-sanitation demonstrations from Germany (CS9).

Two important lessons emerge. Firstly, the value of demonstration projects - in Göteborg (CS4) for example, the reactor did not achieve its performance targets. Fixing this at a small scale entails a small cost, and provides lessons for the next demonstration. Secondly, the need for excellence in collaborative communication at the planning stage, and for ongoing monitoring and evaluation to continue to learn from and improve the performance of the various systems, that we learn from the case studies that have been in successful operation a little longer.

Industry

We focus here on concepts and case studies that are most relevant to industry, ranging across light and heavily regulated industries. Other relevant concepts and case studies that have already been discussed are again shown in grey.

C1 Resources From Waste (IRM) C2 12 R's of Sustainable Water Management C4 Industrial Symbiosis at Kalundborg C5 Biosolids and sustainability C7 Reactors At Interceptors C8 Removing micropollutants	C9 The Ecological Machine at Ethel M C10 Enhanced Role of the Private Sector C11 Nanotechnology C12 3Rs - reduce, reuse, recycle C14 The 21st Century Paradigm C16 Bio-electrochemical systems C17 Novel Membrane Bioreactors
CS1 Treatment of high strength (brewery) waste water CS6 Biogas as vehicle fuel	CS12 Earth Power Technologies - food waste-to-energy facility CS16 Biolytix

Kalundborg in Denmark (C4) is one of the world's best known example of industrial ecology, or industrial symbiosis. The principle here is that co-located industries develop a shared metabolism, through exchanging material flows (one industry's waste becomes another's input) and sharing resources (usually water, steam, and/or energy). What is interesting about Kalundborg is that it emerged naturally. That is, there was no direct intervention, but rather a series of chance ideas over time, and a sense of trust between key managers from different organizations. Around the world, many countries and locations have sought to emulate this. Kwinana in WA is an often-quoted success story. The principle could be much more broadly applied e.g., in an existing high-density area, either through retrofitting or through new brownfield development, such as at Frasers Broadway (CS13), where discussions with UTS are underway to potentially share recycled water systems (for cooling towers or chillers) and digestion systems for energy recovery from sewage and organic solid waste. Such synergies mitigate the supply-demand balance issues exacerbated at very small scale infrastructure, and save space where it is at a premium, by combining two facilities into one.

Here, we highlight two particular technologies that offer excellent opportunities for decentralised treatment of industry by-products, either in retrofits or new installations. The first is familiar, and still undergoing significant development, and that is membranes. In pilot studies on high strength industry sewage (CS1), the anaerobic membrane process produced excellent quality effluent (BOD < 20 mg/L, 1.2 NTU) at a net energy cost of 2.5 kWh/kL. Other novel MBRs (C17) seek to disaggregate the hydraulic retention time and the organic retention time, greatly improving the removal and breakdown of problematic organics. There is a linkage here to nanotechnology (CS11), where one of the advances we explored was nanotechnology developments in membranes to improve specificity of pollutant capture and degradation. This provides an end-of-pipe approach to the issue of problematic pollutants, which will continue to be important even in a society that works with industry to reduce and gradually eliminate such emissions, as Interface are doing in their carpet manufacture.

The second technology we highlight is at an earlier stage of development: bioelectrochemical processes for bio-refining (C16). This technology has also been described as microbial fuel cells. This approach harnesses the innate efficiency of microbially-mediated chemical transformations to capture and harness electrons that then drive further chemical reactions. The range of valuable products from this kind of treatment process is broad, from methane to organic feedstocks for plastic production. Right now, a world-first pilot scale process is operating in Queensland on brewery waste, as part of an integrated system for recovery of resources (energy, sludge, and process water).

Ethel M is a US chocolate manufacturer that was looking for a marketing edge, and needing to respond to increasingly stringent environmental legislation at the same time as upgrading their production capacity. The biomimicry approach provided by the ‘Ecological Machine’ was able to handle their medium strength food waste stream, so it met their needs, whilst provided a nice synergy with their co-located world-famous cactus garden.

5 Overview of case studies

The focus in this section is on the case studies, which are in the main demonstration projects (or potential demonstration projects) which we emphasise as critically important for Melbourne for providing experiential learning. The recommendations we make in Section 6 are grounded in the real life experiences of the case studies listed here.

ISF's goal in this report is to present the outputs of our research in a manner that enables Melbourne Water and its partners to engage with it usefully. With this in mind, in this section we present a brief overview of our case studies grouped within a succinct typology, as an alternative, and complement, to the descriptive presentation in the preceding section. While there is some level of repetition, we expect the information presented in Section 4 and 5 to resonate differently with different members of our client audience.

As noted in Section 4, we have categorised some case studies as concepts when they illustrated a concept that had not been introduced elsewhere (for example, C4 is a case study illustrating the industrial ecology concept). This overview pertains to all case studies categorised as concepts, case studies and virtual case studies: CS1 – 15 and C1,3,4,9,13,16 and 17.

Case Study Typology

The case studies may broadly be categorised as

(a) illustrating specific technologies;
(b) illustrating sustainable residential developments; and
(c) making productive linkages with other resource flow streams.

(a) Technology - research and demonstration projects

The following case studies seek to *increase energy recovery* from sewage as their key focus while producing by-products such as recyclable water and fertilizer:

- CS1 – Australian research to decrease net energy consumption of industrial wastewater treatment (brewery waste);
- CS3 – European demonstration of energy-positive municipal wastewater treatment plant;
- CS6 – European collaborative research to produce vehicle fuel by-product from wastewater streams; and
- CS12 – Australian demonstration of biosolids to energy project.

One case study captures the direct thermal potential of wastewater flowing in sewers:

- CS2 – US based demonstration project using heat exchangers in existing sewers.

Two case studies relate to *wastewater treatment technologies* for producing improved quality effluent :

- C16 - Australian pilot-stage technology for recovering clean water and chemical pollutants; and
- C17 – Singapore/ Australia collaborative lab trial of novel membrane that transmit negligible anounts of endocrine disrupting substances and troublesome micropollutants.

Two case studies demonstrate treatments using *biomimicry:*

- C9 – US based combination of different ecosystems and organism groups for wastewater treatment; and
- CS16 – Australian scalable modular sewage treatment technology available commercially, based on vermiculture and natural organisms.

(b) Sustainable urban residential developments

The following case studies integrate sewerage and other services and resource streams in seeking improved sustainability:

- CS 4, 5, 7 and 9 – European developments using a range of conveyance methods for sewage (vacuum toilets, blackwater separation etc), combined with biogas production and fertilizer production;
- CS13 – Australian development under planning, that will use sewer mining for producing non-potable water and biogas (from anaerobic digestion of biosolids) for co-firing in tri-generation plant; and
- CS11 – Australian development under planning, seeking to balance sustainability objectives with commercial goals through choice of flexibile sewerage infrastructure.

C3 is a case study from China for vertical greenhouse agriculture in combination with high-rise apartments.

Virtual case study CS14 presents a scenario for taking up leading edge hyper-efficient water technologies in the Australian residential sector within the current sewerage infrastructure context.

(c) Productive linkages with other resource flow streams

The *industrial ecology* concept is demonstrated in two case studies:

- C4 – Danish industrial symbiosis creating business-to-business cooperation for resource optimisation; and
- C1 – Canadian application of industrial ecology idea that all resources have value and should be reused, in an urban context for integrated water supply, liquid and solid waste systems.

The concept of *urine diversion* for agricultural re-use is canvassed in two case studies:

- C13 – Swedish case studies implementing the concept for households with transport and re-use by farmers; and
- CS15 – Ghana demonstration project with urine diversion in 14 public urinals in the CBD and re-use in farming.

Two case studies draw on the *stormwater linkages* with sewage:

- CS8 – US innovation for reducing stormwater inflow and infiltration by simple re-lining of sewers, thereby extending useful life and avoiding capacity augmentation of existing infrastructure; and
- CS10 – US approach re-directing stormwater away from sewerage system in low impact urban development using landscape and natural infrastructure.

6 Lessons and Recommendations for Melbourne

Taking this wealth of information together, there are several observations to be made that can inform Melbourne's Strategy.

Undertake pilot and demonstration projects

Pilot and demonstration scale projects will be a key enabler of new approaches to sewerage as noted earlier in this report. The large number of demonstration projects in Europe are a reflection of the EU's generous funding to match its targets for energy and pollution prevention. Similarly in the US, demonstration projects have been critical to advancement in the decentralised sewage industry. Canvassing federal and state governments, and/or establishing community funds specifically to demonstrate technological and institutional arrangement options chosen as part of Melbourne's Sewerage Strategy would enable them to advance to future implementation. This requires the courage to be able to accept and learn from failures.

Generate trust

A key element is socio-political, about how particular decision-making processes have legitimacy in the eyes of the public. Our collaborators in the US identified trust as central here for public acceptance. Developing meaningful relationships is a key part of this.

A further factor for generating trust is when highly respected international bodies demonstrate leadership by stepping into a new space. The World Health Organisation Guidelines for the safe use of wastewater, excreta and greywater (WHO 2006) falls into this category. This recently updated document provides an unequivocal base for the scientific acceptance of concepts such as urine diversion and re-use.

Frasers (CS13) has closely involved an academic institution in the design process, and invested considerable effort to engage with the local community and keep them informed, which all contribute to trust building (Glad, 2008).

As Melbourne considers future residential developments using decentralised infrastructure, designing them in collaboration with the various stakeholders could ease transitions to implementation and improved outcomes.

Collaborate with regulatory authorities

The European residential developments featured here have been collaborations between municipal/local governments, water utilities and developers (CS 4, 7 and 9), while academic institutions have been involved in others (CS 4, 5 and 9). Collaborative processes of design are more likely to smooth the processes for gaining necessary approvals, especially if the approving authorities are involved. Academic associations also likely build credibility about the rigour of investigations behind designs. As noted above, collaboration builds trust which is key to success.

New institutional arrangements will be part of the new technologies and approaches. Garnering support for these, and ensuring they are designed to meet long term needs, such as the proprietising of sewage and its constituent parts (i.e. the conferral of property rights such that ownership is possible and can be transferred and sold), will be critical to achieving sustainable outcomes.

Maximise value from existing assets

It is prudent to get as much use from the existing assets as possible while making a transition to a different infrastructure, as noted in the concept of “run to failure” (C 6). Making a relatively low investment in repairing sewers to reduce stormwater infiltration (CS8) does this without creating commitment to the technology that accompanies high levels of investment. CS8 observes that as sewers became redundant with a move to decentralised systems, the sewer cavities could be put to use for other purposes such as carrying smaller diameter pipes – for example, pipes in a recycled water grid (C20) or distributed wastewater network (C15).

Heat recovery from sewage in sewers (CS2) again increases the net benefit from existing infrastructure. In this case however, care is needed to design the system so that transition to a decentralised configuration is possible. It could mean that this technology is best implemented on a small scale.

The hyperefficient homes for tomorrow (Virtual CS14) shows a technological solution to the potentially problematic situation of low-flows in existing sewers, enabling current infrastructure to be used in a smooth transition to future decentralised infrastructure.

Recognise interactivity between technology and behaviour

Designs of new technological options that are potentially radically different to current infrastructure are a key part of the Melbourne Strategy process. At the same time, plans for community education and engagement programs are needed as part of a successful implementation plan. The Hammarby experience (CS7) showed that the performance of many technologies are affected by user behaviour, and can fail without accompanying education and training (Drangert, 2008)

Pay attention to residuals

Of all the case studies considered, only the industrial ecology case study (C 4) addressed capture of residuals such as heavy metals. Although the City of Göteborg (CS4) project was created by the desire to keep residuals out of biosolids, the final fate of the residuals is not described in the literature. Jan-Olof Drangert (2008) made the observation that residuals are of little interest to the general public beyond having it taken away, but it is of value for some industrial sectors and hence capture and re-use is beneficial. Residuals management may be a challenge for Melbourne whether centralised or decentralised systems are used, and an intentional effort to manage them in beneficial ways would be required.

A key concept here is the advocacy role of water authorities in seeking a new approach to problematic residuals. Various options exist, including adapting the EPR framework. Water authorities are in a prime position to lead this, since their capacity to provide products and services is inadvertently impeded by chemicals and pharmaceuticals manufacturers.

Apply the n-R’s principle system-wide

Application of the principle to Reduce, Reuse, Recycle, Reclaim, Recover etc on a system-wide scale increases the net benefits. This is demonstrated by the industrial ecology case study (C 4) that reduced economic costs across the system as well as polluting impacts of residuals. Likewise the integrated resource management case study (C 1) reduced costs for sewerage services across a province. Restoration of green infrastructure (CS 10) provides system-wide benefits such as increasing evaporative cooling of cities and reducing energy demand.

Balance short-term and long-term actions

Unless carefully designed, innovations to gain greater benefits out of existing infrastructures (such as large scale sewer mining and sewer heat recovery) can inadvertently create a need to maintain sewage flows in conventional sewers, undermining more sustainable options, such as water efficiency programs and decentralised systems. Careful design is needed to ensure that the scale of such innovations are balanced between being big enough to be balanced and profitable, and small enough to avoid rigidity and retain flexibility.

Another transitional issue is sewage concentration as new concepts including water efficiency and greywater reuse reduce water flows in conventional sewers. Research programs that address potential transitional problems would thus form an important element for intentionally moving to a future sewerage system that is different from the current one.

Table 1: Applicability by development type

	Concept/Case Study	Location		Occupancy (wastewater type)				Dwelling density		City wide
		New green/ brown field	Existing retrofit/ redevelop	Residential	Commercial – non-reg.	Commercial – light reg.	Heavy Industry	Activity centre	Low density	
	Concept									
C1	Resources From Waste: An Integrated Approach to Managing Municipal Water and Waste Systems	✓	✓	✓	✓	✓		✓	✓	✓
C2	Water 2030 -- The Twelve R's of Sustainable Water Management	✓	✓	✓	✓	✓	✓	✓	✓	✓
C3	Agro-Housing	✓		✓				✓		
C4	Industrial Symbiosis at the City of Kalundborg, Denmark	✓	✓			✓	✓			
C5	Biosolids and Sustainability: The Natural Step 2020 Visioning Project		✓	✓	✓	✓	✓			
C6	“Run to Failure” Management and Transition to New Approaches		✓					✓	✓	✓
C7	Reactors At Interceptors for Flow Control, Flow Distribution and	✓	✓	✓	✓	✓	✓	✓	✓	✓

	Concept/Case Study	Location		Occupancy (wastewater type)				Dwelling density		City wide
		New green/ brown field	Existing retrofit/ redevelop	Residentia l	Commercia l – non-reg.	Commercia l – light reg.	Heavy Industry	Activity centre	Low density	
	Reuse									
C8	Removing endocrine-disrupting compounds (EDCs), pharmaceutically active compounds (PhACs), and personal care products (PCPs)	✓	✓	✓	✓	✓	✓	✓	✓	✓
C9	The Ecological Machine at Ethel M Chocolates	✓	✓	✓		✓		✓	✓	
C10	Enhanced Role of the Private Sector	✓	✓	✓	✓	✓	✓	✓	✓	✓
C11	Nanotechnology for wastewater treatment	✓	✓	✓	✓	✓	✓	✓		
C12	Every house and entity – reduce, reuse, recycle	✓	✓	✓	✓	✓	✓	✓	✓	✓
C13	Urine diversion and reuse in Australia: lessons learnt from the Swedish experience	✓	✓	✓	✓			✓	✓	
C14	Decentralized Water Infrastructure – The 21st Century Paradigm	✓	✓	✓	✓	✓	✓	✓	✓	✓

	Concept/Case Study	Location		Occupancy (wastewater type)				Dwelling density		City wide
		New green/ brown field	Existing retrofit/ redevelop	Residentia l	Commercia l – non-reg.	Commercia l – light reg.	Heavy Industry	Activity centre	Low density	
C15	Distributed wastewater network	✓	✓	✓	✓	✓	✓	✓	✓	✓
C16	Bio-electrochemical systems for biorefining of wastewater	✓	✓			✓	✓	✓		
C17	Novel Membrane Bioreactors	✓	✓			✓	✓	✓		
C18	No potable supply									✓
C19	Decentralised Sanitation and Reuse (DESAR) with Virtual case study	✓	✓	✓	✓			✓		
C20	Recycled water grid	✓	✓	✓	✓	✓		✓		
	Case Study									
CS1	Treatment of high strength (brewery) waste water	✓	✓				✓			
CS2	Sewer Heat Recovery	✓	✓							✓
CS3	Strass Austria - Energy Neutral wastewater treatment	✓	✓	✓	✓			✓		
CS4	System Study Wastewater and Biowaste in Gothenborg	✓		✓	✓			✓	?	

	Concept/Case Study	Location		Occupancy (wastewater type)				Dwelling density		City wide
		New green/ brown field	Existing retrofit/ redevelop	Residentia l	Commercia l – non-reg.	Commercia l – light reg.	Heavy Industry	Activity centre	Low density	
CS5	The zero emission university	✓	✓							
CS6	TRENDSETTER EU project – biogas as vehicle fuel			✓	✓	✓				
CS7	Hammarby Sjöstad case study	✓		✓				✓		
CS8	King County Regional Inflow/Infiltration Program		✓	✓	✓					✓
CS9	Ecological housing estate Lübeck Flintenbreite, Germany	✓		✓				✓		
CS10	Sustainable Infrastructure: Green Stormwater Infrastructure/Low Impact Development Toolkit	✓	✓	✓				✓	✓	✓
CS11	Rocky Springs	✓		✓	✓			✓	✓	
CS12	Earth Power Technologies - food waste-to-energy facility	✓	✓		✓	✓				
CS13	Frasers Broadway	✓		✓	✓			✓		
CS14	Hyper Efficient Homes for Tomorrow	✓	✓	✓				✓	✓	
CS15	Urine separation pilot SWITCH	✓	✓		✓					✓

	Concept/Case Study	Location		Occupancy (wastewater type)				Dwelling density		City wide
		New green/ brown field	Existing retrofit/ redevelop	Residential	Commercial – non-reg.	Commercial – light reg.	Heavy Industry	Activity centre	Low density	
CS16	Biolytix	✓	✓	✓	✓	✓			✓	

Table 2: System elements coverage

	Concept/Case Study	Up-stream	Collect'n Convey-ance	Treat-ment	Productive Re-use	Residuals manage-ment
	Concept					
C1	Resources From Waste : An Integrated Approach to Managing Municipal Water and Waste Systems	✓	✓	✓	✓	✓
C2	Water 2030 -- The Twelve R's of Sustainable Water Management	✓	✓	✓	✓	✓
C3	Agro-Housing	✓	✓	✓	✓	
C4	Industrial Symbiosis at the City of Kalundborg, Denmark	✓	✓	✓	✓	
C5	Biosolids and Sustainability: The Natural Step 2020 Visioning Project	✓		✓		✓
C6	"Run to Failure" Management and Transition to New Approaches		✓	✓	✓	
C7	Reactors At Interceptors for Flow Control, Flow Distribution and Reuse		✓	✓	✓	
C8	Removing endocrine-disrupting compounds (EDCs), pharmaceutically active compounds (PhACs), and personal care products (PCPs)	✓		✓	✓	✓
C9	The Ecological Machine at Ethel M Chocolates		✓	✓	✓	✓
C10	Enhanced Role of the Private Sector	✓	✓	✓	✓	✓
C11	Nanotechnology for wastewater treatment			✓	✓	
C12	Every house and entity – reduce, reuse, recycle	✓		✓	✓	
C13	Urine diversion and reuse in Australia: lessons learnt from the Swedish experience	✓			✓	
C14	Decentralized Water Infrastructure – The 21st Century Paradigm	✓	✓	✓	✓	

	Concept/Case Study	Up-stream	Collect'n Convey-ance	Treat-ment	Productive Re-use	Residuals manage-ment
C15	Distributed wastewater network		✓	✓	✓	
C16	Bio-electrochemical systems for biorefining of wastewater			✓	✓	
C17	Novel Membrane Bioreactors			✓	✓	
C18	No potable supply	✓				
C19	Decentralised Sanitation and Reuse (DESAR) with Virtual case study	✓	✓	✓	✓	✓
C20	Recycled water grid		✓	✓	✓	
	Case Studies					
CS1	Treatment of high strength (brewery) waste water			✓	✓	
CS2	Sewer Heat Recovery				✓	
CS3	Strass Austria - Energy Neutral wastewater treatment			✓	✓	
CS4	System Study Wastewater and Biowaste in Gothenborg	✓	✓	✓	✓	
CS5	The zero emission university	✓	✓	✓	✓	
CS6	TRENDSETTER EU project – biogas as vehicle fuel			✓	✓	
CS7	Hammarby Sjöstad case study	✓	✓	✓	✓	
CS8	King County Regional Inflow/Infiltration Program		✓			
CS9	Ecological housing estate Lübeck Flintenbreite, Germany	✓	✓	✓	✓	
CS10	Sustainable Infrastructure: Green Stormwater Infrastructure/Low Impact Development Toolkit	✓	✓			
CS11	Rocky Springs		✓	✓	✓	
CS12	Earth Power Technologies - food waste-to-energy facility	✓		✓	✓	✓
CS13	Frasers Broadway	✓	✓	✓	✓	
CS14	Hyper Efficient Homes for	✓	✓			

	Concept/Case Study	Up-stream	Collect'n Convey-ance	Treat-ment	Productive Re-use	Residuals manage-ment
	Tomorrow					
CS15	Urine separation pilot SWITCH	✓			✓	
CS16	Biolytix		✓	✓	✓	

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Appendix 1: Collaborators

NAME	Affiliation	email
Tracey Adams	Biolytix Water Australia Pty. Ltd., Australia	tracy.adams@biolytix.com.au
Cori L. Barraclough & Patrick Lucy	Aquatex Scientific, Canada	aqua-tex@islandnet.com
Dana Cordell	Linkoping University, Sweden and Institute for Sustainable Futures	Dana.Cordell@uts.edu.au
Assoc. Prof. Jan-Olof Drangert	Linkoping University, Sweden	jandr@tema.liu.se
Prof. Tony Fane	UNESCO Centre for Membrane Science and Technology, University of NSW	a.fane@unsw.edu.au
Dr. Therese Flapper	Alchemy Sciences Pty Ltd, Australia	tflapper@ozemail.com.au
Carol Howe	SWITCH, The Netherlands	c.howe@unesco-ihe.org
Prof. Petter Jensen	Norwegian University of Life Sciences	petter.jenssen@umb.no
Craig Lindell	Aquatech, USA	chlindell@aquapoint.com
Steve Moddemeyer	CollinsWoerman, USA	smoddemeyer@collinswoerman.com
Dr.Valerie Nelson	Coalition for Alternative Wastewater Treatment, USA	Valerie508@aol.com
Korneel Rabaey	Advanced Water Management Centre, University of Queensland	k.rabaey@uq.edu.au
Aaron Spicer	Lend Lease Ventures, Australia	aaron.spicer@lendlease.com.au
Jerry Stonebridge	NOWRA President, USA	stonebrg@whidbey.com