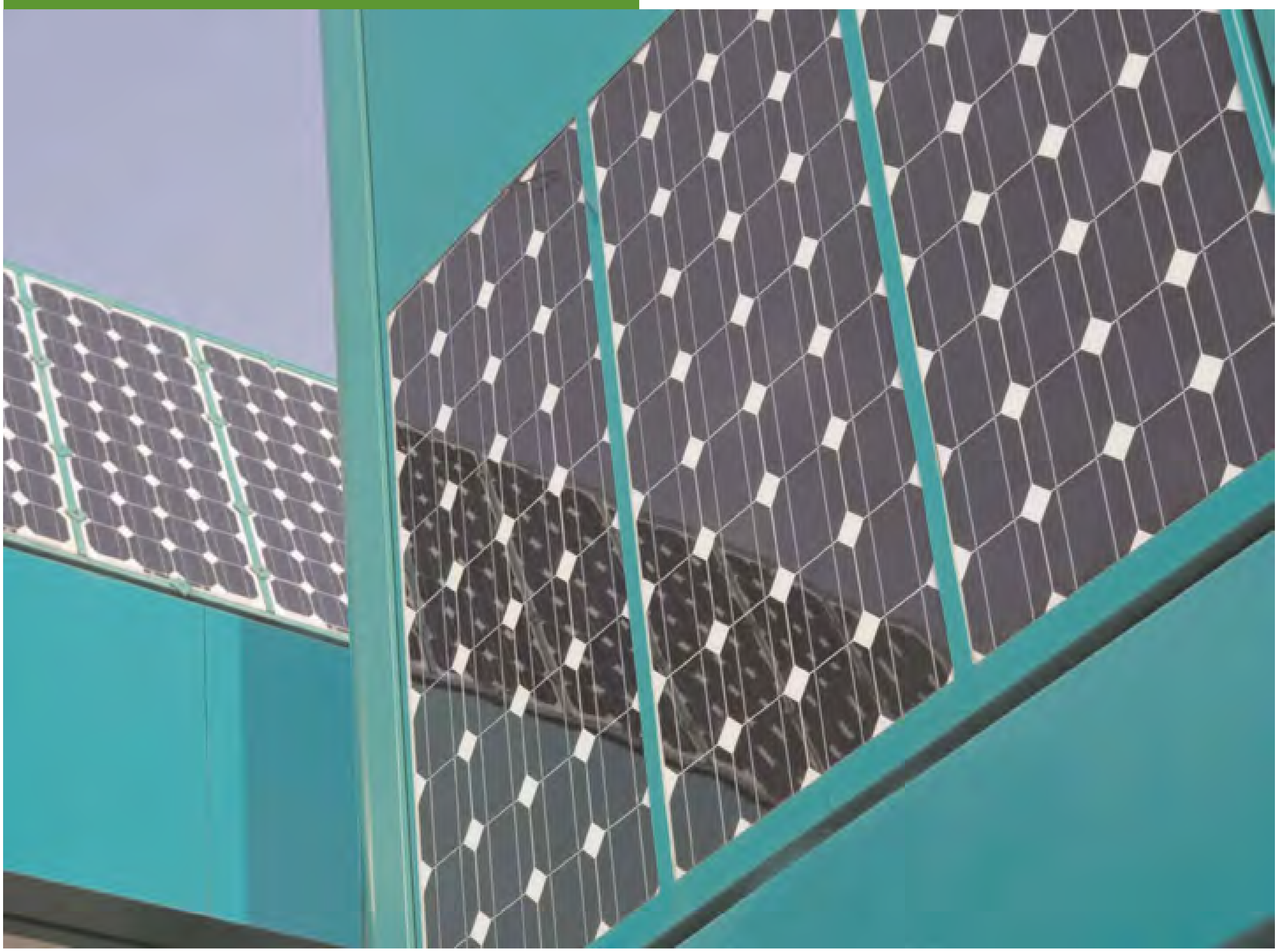
Green Infrastructure

Demonstrating the Economic Benefits of Integrated, Green Infrastructure

MARCH 2004



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DEMONSTRATING THE ECONOMIC BENEFITS OF INTEGRATED, GREEN INFRASTRUCTURE

Centre for Sustainable Community Development

FINAL REPORT

Prepared for the Federation of Canadian Municipalities

March 2004

ABSTRACT

The pressing need for communities and municipalities to find the financial means of addressing infrastructure and service requirements in the face of deteriorating environmental health, social, and fiscal conditions calls for the development of innovative strategies that yield greatly improved life-cycle performance over current methods.

The criticality of these matters encompasses climate change, declining energy, water, land and material resources; pollution of air, water and soil; ecological and human health; food and nutrient cycles; security and reliability; social well-being and more.

Among sustainable design and planning practitioners, it is understood that breakthrough approaches are found in the synergies inherent in comprehensive and integrated solutions.

Much has been accomplished in related fields of green buildings, industrial ecology, and ecosystem planning. By reframing problem solving and planning from a more holistic perspective, countless opportunities arise to accomplish more with less capital investment. Appropriateness of scale and degrees of autonomy vs. interconnectedness are important considerations in capturing integrities, staging investments and building resilience. A related matter is the consideration of the demand/supply equation and treating end use investment on the same basis as production investment.

Typically, the current administrative structure of municipal government and its relationship to the private sector and civil society, can pose significant barriers to developing integrated approaches to sustainable infrastructure and community services. Likewise, current governmental fiscal policy and management reinforces this compartmental culture.

This paper will provide a compelling argument for municipalities to pursue means of developing integrated approaches in the development of services and infrastructure. Real world and generic illustrations are provided to demonstrate the compelling reasons why municipalities are and should be moving towards integrated green infrastructure approaches. The intent of this report is to illustrate the economic, social, fiscal and environmental benefits of cooperative planning and development and to provide guidance to municipalities as they forge ahead.

Ultimately, this report argues for applying the structure of ecology as "nested integrities" to planning for the functional attributes of sustainable communities, cities and regions.

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INTRODUCTION

In the context of municipal planning and infrastructure investment, the prudent application of limited financial resources may at first appear as a constraint to sustainable development. However, there is growing evidence that strategies and technologies supportive of sustainability are possible, relevant and provide services at lower costs and even at lower capital investments than conventional approaches. Conventional approaches to infrastructure, although continuously being improved, have usually been undertaken as separate departmental and therefore compartmental activities. Maximizing cost effectiveness for individual functions generally results in sub-optimal economic performance of total services.

Municipalities are pursuing new and upgraded infrastructure that supports community needs in the most economic manner. Many recognize that applying an integrated approach to sustainable community planning can provide “win-win-win” solutions, decision-making based on the triple bottom line, which takes economics, environment, and society into account. This study examines the prospects and provides case studies for cost-savings that result from coordinated approaches to urban infrastructure. By taking advantage of the synergies presented by system integrations, with a focus on sustainable functioning, it is possible to reduce capital and operating costs while improving the intended environmental and social benefits.

There is a widely held belief that in order to protect ecological integrity and sustain the material and energy resources for human consumption, costs will increase and the economy will suffer. A deeper look however, reveals that continued erosion of natural capital (e.g. soil, water, land, forests) will undermine the viability of society, so dependence on a continuous harvest of biologically and solar derived resources will need to grow to replace those that are dwindling or polluting.

Drinkable water, breathable air, nutritious food, reliable energy, and useful materials are ultimately dependent on a healthy, functioning biosphere. Likewise, the stability and capability of our neighbourhoods and communities is derived from equitably distributed production and our ability as individuals and organizations to contribute to providing our collective needs. Social and natural capital is fundamentally bound to ecological integrity that results from sustainable forms of development. Economics is a discipline and tool that orchestrates the means of serving human needs sustainably.

Our challenge then is to redesign our modes of production and living such that we depend entirely on solar income, the continuous cycling of materials, and the health of the biotic community in a manner that is guided by economics. In turn, fiscal policy needs to be directed by appropriate accounting of social and natural capital to determine whether production is truly profiting society rather than depleting its capital.

TYPES OF GREEN INTEGRATIONS

The following attributes of integrated and green infrastructure are illustrated by the real world case studies beginning on page 12 of this report.

1) A focus on end use where demand-side management (DSM) and efficiency measures effect savings in source supply and service capacity

Demand-side management (DSM) refers to a host of activities that focus on reducing demand for water, gas, and electricity either in the form of utility interventions, facility, or household efficiency alterations. A focus on end use recognizes the involvement of the homeowner, facility operator or at the larger scale, the utility, in resource conservation. Utilities offer financial incentives, goods, or services in order to achieve energy or water saving goals and related cost savings in the form of rebates, for example. The installation of technologies or equipment such as energy or water saving devices, renewables, and even the operation and maintenance of the utility contribute to efficiencies and cost savings. In the case of the homeowner, there is a voluntary incentive to install efficiency devices to achieve a direct saving, whereas the utility incentive aims to achieve an overall reduction in demand on the utility. Government agencies and municipalities enjoy the benefits of DSM in measured performance that achieves energy and water utility cost savings in the operation of facilities and buildings, and by the eliminated need for their expansion or reconstruction. DSM can also refer to energy audits, facility design, and process enhancements as well as training of client or personnel to effectively install, operate, and maintain the system. These investments are seen to significantly reduce capital outlay for infrastructure investments, so it is critical to imbed DSM programs into infrastructure investment planning, development, and management.

2) Multiple functions served by common devices

Today's urban infrastructure can be examined in terms of its potential to serve multiple utility functions within existing capacities and to avoid the development and construction of new infrastructure wherever possible. Inherent in the multiple functions approach is the concentration of various infrastructure components. The notion of "green infrastructure" presumes multiple crossover or "integration" functions in its approach. For example, components of today's buried infrastructure (water, electricity, cable, sewage, fibre optics) are regularly concentrated into road design. Integrated, green infrastructure combines infrastructure components within the existing trench and adds efficiency components such as separation of blackwater and greywater reuse, or heat transfer from one medium to another. The utilidor concept is a single utility trench that accommodates many infrastructure needs along with surface corridor or right-of-way enhancement functions. Additional concentrated functionalities can include stormwater infiltration and treatment, greenways, bio-swales, or urban forests and technologies designed for accessibility and reduced maintenance.

3) Secondary resource value available in a service

The selection of infrastructure technologies and systems can often yield useful bi-products or secondary resources. For example, in nature, wastes become a resource when plant and fecal matter biodegrade and add nutrients to the soil. Similarly, in urban environments, wastewater and organic waste are resources, which can be processed into nutrients for horticultural uses, methane for energy production and purified water for secondary reuse. "Waste" heat that is generated with cogeneration technologies and stack heat recovery can displace fuel-fired facilities. Today's recycling programs model an exemplary practice in waste recovery, reuse, and optimizing resource value. These programs have illustrated both the cost benefits and market challenges that result from the necessity for many municipalities to divert waste from landfills. Avoided costs associated with constructing and operating landfills, leachate treatment, and environmental pollution along with continued public pressure, land area limitations and a steady increase in packaging and waste have demanded the approach. However, similar untapped opportunities exist for water, energy and wastewater systems to maximize secondary resource value in service.

4) Compatibility of siting and placement (co-location)

Efficiencies of land use and synergies between functions can often be realized through siting and placement of compatible facilities. For example, a wastewater treatment facility could also deploy on-site wind turbines should the conditions be suitable. For example, plant roofs could incorporate solar panel concentrations for electrical generation and heat or methane-fuelled cogenerators could be made operative using plant biogas. These types of integrations offer many advantages including but not limited to: emergency power provisions for the plant, assured solar and wind exposure through plant design, waste heat use, embedded generation connected to large electrical transmissions and noise isolation. These integrations may involve public/private partnerships that offer financial benefits such as income to municipalities.

5) Creation of social amenities as intrinsic attributes

Many green approaches to infrastructure add value to the communities they serve and society as a whole. In fact their social contribution is an equally important selection criteria to their environmental benefit. For example, non-structural stormwater management retention ponds and swales embody and enhance a biologically diverse landscape and serve as parks and passive recreation areas. Ecological wastewater treatment plants or "ecological machines" double as indoor gardens and improve indoor air quality. Photovoltaic canopies can be designed to provide shade and pedestrian shelter simultaneously. Pedestrian and cycling routes provide both functional movement of people, water and small mammals and birds, recreational and tourist assets, while reducing the number of automobiles on the road, smog, and climate change. Community centres could act as local power centres providing both amenity and function (this also illustrates the co-location principle). All in all, integration in the form of multiple benefits or "win-win-win" solutions is a core aim of sustainable thinking.

6) Matching resources to end-use requirements

Today's approach to infrastructure is relatively one-dimensional in terms of the process of providing water, energy, or processing waste from source to sink. However, opportunities exist to increase the sophistication of infrastructure so that resources are more efficiently processed, treated, and utilized to make the most out of the supply stream and to reduce waste. The concept of "matching" refers to linking the highest quality resources with the most appropriate and demanding end uses while developing secondary and even tertiary systems to capture and match lower grade end uses. As water, energy, and materials are used they decline in quality but are reassigned to an appropriate use. For example, potable water is currently used for all water needs including toilet flushing, laundry, and irrigation. The Canadian Water Quality Association estimates that water used for human consumption accounts for only one-half of one percent of total community water use of 175 gallons per capita per day, leaving remaining greywater as a vastly underutilized resource. A more efficient use of this precious resource would direct potable water for drinking purposes only and non-potable water for other uses through a series of processes including blackwater and/or greywater separation, reclamation, and reuse following secondary or tertiary treatment.

7) Engaging natural (biological and passive) functioning in service provision

Human communities are sustained by the stored wealth of resources available to us. Green infrastructure aims to maximize the use of on-site resources and to even incorporate them or mimic biological processes in the design of built human systems. By increasing infrastructure reliance on passive functioning such as gravity, geothermal energy, or sunlight and wind, we virtually make use of free services from nature without exploiting non-renewable systems. These localized approaches help define our communities and make them unique, resilient, and sustainable. It should be noted that the incorporation of local resources into the development of integrated green infrastructure should be approached with sustainability and enhancement of the natural environment and community as key objectives. The disciplines of ecological engineering and green infrastructure look for these synergies and engage the complex needs of infrastructure planning while mimicking biological relationships.

8) Strengthening local resilience to external and internal disruptions

Infrastructure needs to be designed to resist disruptions caused by extreme weather events or anticipated and unanticipated demands on the system. The disruptions we face today are substantially different than the threats we faced 20 years ago. Incidences such as power shortages, security issues, computer viruses, and natural disasters can strain or disrupt basic urban survival systems. A more resilient infrastructure is capable of adapting to larger system disruptions by reverting to failsafe modes. For example, the emerging modifications to the North American power grid include an emphasis on distributed, local, renewable generation. Multiple sourcing, closed-loop systems and on-site harvesting add resilience in cases where imported resources are affected and limited by external events.

By adopting integrated green planning and design practices, municipalities can realize major savings to capital and operating costs while creating healthier, safer, more affordable, and ultimately, sustainable communities. The sections to follow elaborate on this premise and provide evidence to this claim.

For additional information on the features and benefits of Green Infrastructure, refer to ***Green Municipalities: A Guide to Green Infrastructure for Canadian Municipalities***[1].

STUDY APPROACH

This study involves testing and demonstrating the proposition that integrated, green infrastructure approaches are more economically attractive than conventional or current practice. In order to test and demonstrate this premise we conducted a number of stages to the research.

Stage 1

First we conducted a scan of existing "real-world" case studies across Canada to gauge the extent to which Canadian municipalities and their partners have developed integrated, green infrastructure over conventional infrastructure. As part of this exercise we needed to understand the motivation for municipalities as well as the challenges they face in trying to implement new approaches. We spoke to experts who understand ecological design and integrated, green infrastructure and reviewed best practice reports to identify some of the best projects being undertaken. From a broader list we narrowed down to approximately ten projects and contacted the municipalities or project leads to scope the relevance of the project for this study further. The project had to meet the following criteria to be eligible to feature in this study:

- The project needed to demonstrate the synergies between at least two different components of infrastructure and the types of green integrations presented I the previous section.
- We required costing data for that particular integration.

We arrived at four "real-world" case studies, which by no means represent the ideal in integrated, green infrastructure approaches, but they do illustrate a movement by Canadian municipalities in this direction.

[1] Sheltair Group, 2001. *Green Municipalities: A guide to Green infrastructure for Canadian Municipalities*. Prepared for the Federation of Canadian Municipalities.

In order to demonstrate some of the higher level ideals and opportunities already achieved by more integrated, green approaches elsewhere we selected two "real-world" international case studies which we describe generally to illustrate the possibilities of adapting these types of advanced systems here in Canada.

Simultaneously we developed an analytical framework to assess the potential infrastructure synergies. The framework identifies eight infrastructure components, mainly hard services, and cross-references them in order to identify potential relationships and integrated, green technologies and solutions. A working relationships matrix was produced and is appended to this report (Appendix B), which identifies two-dimensional infrastructure relationships. There is certainly potential to significantly expand the matrix to illustrate multi-dimensional service relationships.

Stage 2

The second major component of this study is the "theoretical" case studies. From our own understanding and the insights developed in the first phase of work, three "clusters" of potentially very strong service relationships were identified. The three "clusters" were identified on the basis that they offer the highest levels of potential integration according to the Types of Green Integrations outlined in the previous section of this report. The "theoretical" examples provide an opportunity to imagine the possible scenario and to fully elaborate the potential cost considerations including projected economic, social and environmental costs and benefits. We quantified capital and operating costs and benefits, and qualified social and environmental externalities.

COSTING METHODOLOGY

The costing methodology applied in this study is based on the Conceptual Framework for Costing outlined in a recently completed CMHC costing study[2]. The steps involved in costing the theoretical scenarios presented in this report include:

1) Development of generic costs for each hard infrastructure component on a per unit basis.
2) Calculations of costs for each infrastructure category (conventional approach and integrated, green approach) based on generic unit costs and feedback/correction from Dillon Consulting as a third party. From the unit costs, we determined the site cost for our hypothetical scenario.
3) Calculation of 10-year costs based on operating costs and replacement costs. Replacement costs we calculated as the amortized annual mortgage based on the component's life-span.
4) From the 10-year costs, we determined the net revenues or cost-savings between conventional and integrated, green infrastructure scenarios.

[2] Dillon Consulting et al. 2003. *CMHC Costing Mechanism to Facilitate Sustainable Community Planning, Draft Report, Phase 1 – Background Research and Costing Framework*.

DEFINITIONS

For the purposes of this study:

Hard infrastructure generally refers to physical infrastructure required to directly support neighbourhood development, either on-site as with local roads and sewers or off-site as with regional scale facilities such as wastewater treatment plants and power-generating stations. Components of the food distribution system have been included since they are fundamental to fully functional neighbourhoods.

Capital costs largely refer to direct costs of building hard infrastructure components. These costs make up the majority of conventional accounting.

Operating costs are tied to the initial capital costs as they involve the long-term maintenance and day-to-day operation of infrastructure.

Replacement costs refer to the cost of entirely replacing a piece of infrastructure at the end of its useful life.

External costs refer to indirect costs that are neither priced nor paid for through conventional accounting or market mechanisms. They are either unrecognized costs such as environmental impacts, not well understood or not paid for by the developer/municipality so go unrecorded. They are noted qualitatively in this study to begin to account for the broader social and environmental impacts and benefits of integrated, green infrastructure approaches.

Full-cost accounting takes into consideration all of these costs whether or not dollar values have been assigned in order to provide a full-picture of the real costs associated with an undertaking. In many cases conventional infrastructure is more costly than integrated approaches when full-cost accounting is applied.

STUDY LIMITATIONS

- This study was conducted within a two-month period restricting the level of data and analysis to what was possible within that time frame.
- Level of cost data for the “real-world” case studies varies depending on what was available and public information.
- Costing numbers for the “theoretical” case studies are estimated and provide relative comparison. The numbers are based on the knowledge and experience of the study team including Sustainable EDGE, The Mitchell Partnership, and Dillon Consulting.

ANALYTICAL FRAMEWORK

The basic analytical framework used for this study begins with a raw list of infrastructure components, both hard and soft to define the basic infrastructure components being considered here and the degree of relationship between them. The working matrix (Appendix B) was then developed to examine the potential service interrelationships more closely beginning with two-dimensional relationships and then considered for multi-dimensional opportunities. Figure 1 depicts the best synergistic relationships possible among core infrastructure components regardless of owner and operator. The strongest relationships provide optimum opportunities to develop integrated, green infrastructure technologies or solutions.

PRIMARY (HARD) INFRASTRUCTURE

WATER SUPPLY

Sourcing
Treatment
Pumping & Storage
Distribution & Metering
Non-potable supply
Water conservation

WASTE WATER

Conveyance
Treatment
Discharge
Biosolids management
Site level treatment

STORMWATER

Surface reception/ flow
Conveyance
Retention/detention
Treatment
Discharge

ENERGY

Electrical distribution, transformers, metering
Electrical generation
Gas distribution, metering
District heating and cooling
Energy management
Other fuels supply/ storage

TRANSPORTATION

Roads, sidewalks, pathways
Docking
Airports
Railways
Public transit
Parking facilities
Municipal vehicles
Street cleaning and snow removal

MUNICIPAL SOLID WASTE

Collection
Materials processing & separation
Haulage
Disposal & landfill
Waste reduction & diversion

FOOD

Public markets
Food terminals, distribution
Urban agriculture
Food banks

SECONDARY (SOFT) INFRASTRUCTURE

EMERGENCY SERVICES
Firefighting, fire protection
Police
Ambulance
Emergency response

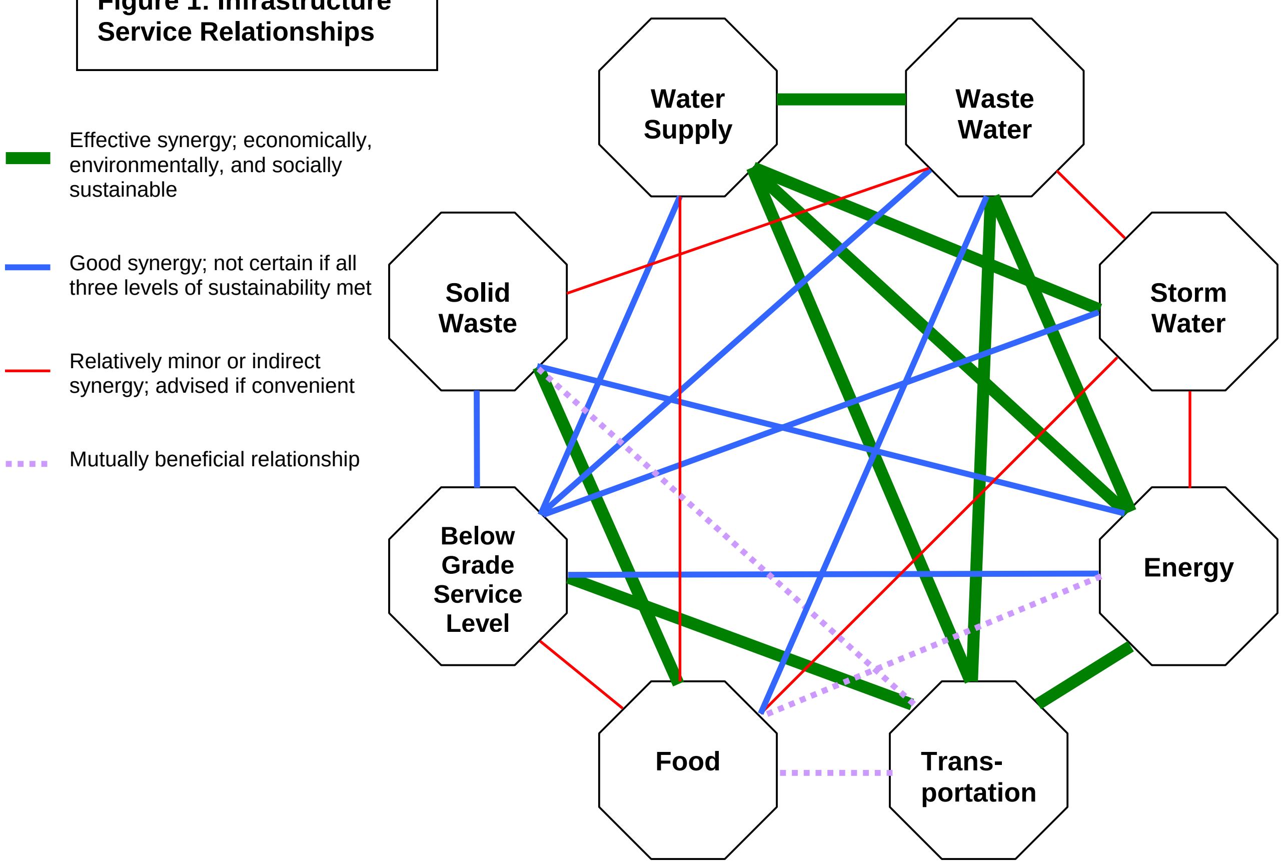
PUBLIC HEALTH
Environmental protection
Disease control
Public health units
Hospitals & healthcare units

PARKS & RECREATION
Parks operations and maintenance
Recreation facilities
Public facilities & community centres

SOCIAL SERVICES
Social housing & shelter
Education
Welfare
Employment & training
Arts, public events

COMMUNICATIONS
Telephone
Cable
Airwaves
Public information

Figure 1: Infrastructure Service Relationships



STAGE 1 RESULTS: "REAL WORLD" DEMONSTRATIONS

1) TORONTO DEEP LAKE WATER COOLING PROJECT, ONTARIO (Type 2, 3 & 7 Green Integration)

The demand for air conditioning in cities has risen dramatically over the last decade. Ontario's peak electricity demand now occurs from air conditioning rather than heating over winter. Brownouts and blackouts occur during heat-waves across North America. The CFCs used in conventional chillers contribute to ozone depletion and coal-fired generating plants contribute to air pollution, acid rain, and climate change.

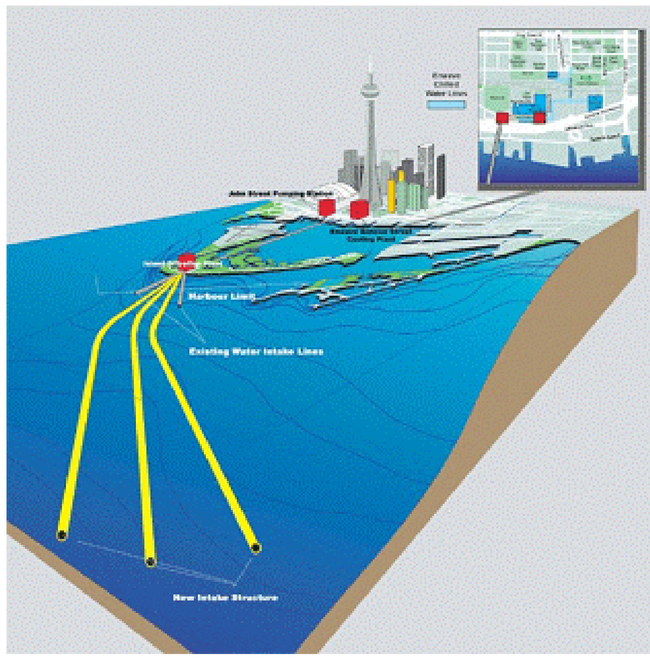


Figure 2: Deep Lake Water Cooling Schematic

In the City of Toronto, with a population of over 2.4 million, over half of the annual cooling load goes to counteract the heat produced by people, lights, IT/telecom equipment and offices regardless of the time of year. In the early 1990's Toronto, located on the edge of Lake Ontario, started to look into the benefits of Deep Lake Water Cooling (DLWC) as a localized, sustainable energy solution using a renewable cooling source. A Deep Lake Water Cooling Investigation Group was established with representation from energy and environmental experts, agency, and municipal staff to oversee the research program for the project. The investigation group strongly recommended the rapid installation of a district cooling system in downtown Toronto fed by cold Lake Ontario water "within the framework of a program implementation of technically and economically feasible measures to reduce cooling demand."

In 1996, Toronto Water Supply (TWS) and Enwave District Energy Limited, a private energy company, entered into a mutually beneficial partnership to develop a lake cooling system that would integrate with the City's water supply. TWS required new water intakes for the Island Filtration Plant to improve local water quality and were looking at accomplishing this through moving the intakes further out into the lake at a greater depth (Figure 2). They were also looking at upgrading and winterizing the plant. Enwave was investigating how to meet increasing loads from new downtown developments and the need to replace CFC refrigerant plants in existing buildings by 2005. The merging of these interests in the DWLC project used the synergies of collective needs to reduce the total costs of both parties' requirements while creating energy-saving, sustainable source cooling for up to 20% of the downtown building load.

The construction of the system was launched in 2002. As shown in Figure 3, the treated lake water is fed from the Island Filtration Plant to Enwave's energy transfer station where it enters 18 pairs of plate and frame heat exchangers that separate the two water streams – the potable water supply and the district cooling loop. The treated lake water enters the energy transfer station at a temperature of between 2.5 and 4 degrees Celsius depending on the season and leaves the energy transfer station at 12.5 degrees C. During summer months the water can be further cooled as needed. The ultimate capacity of the system is 52,000 Tons of Refrigeration (TR).

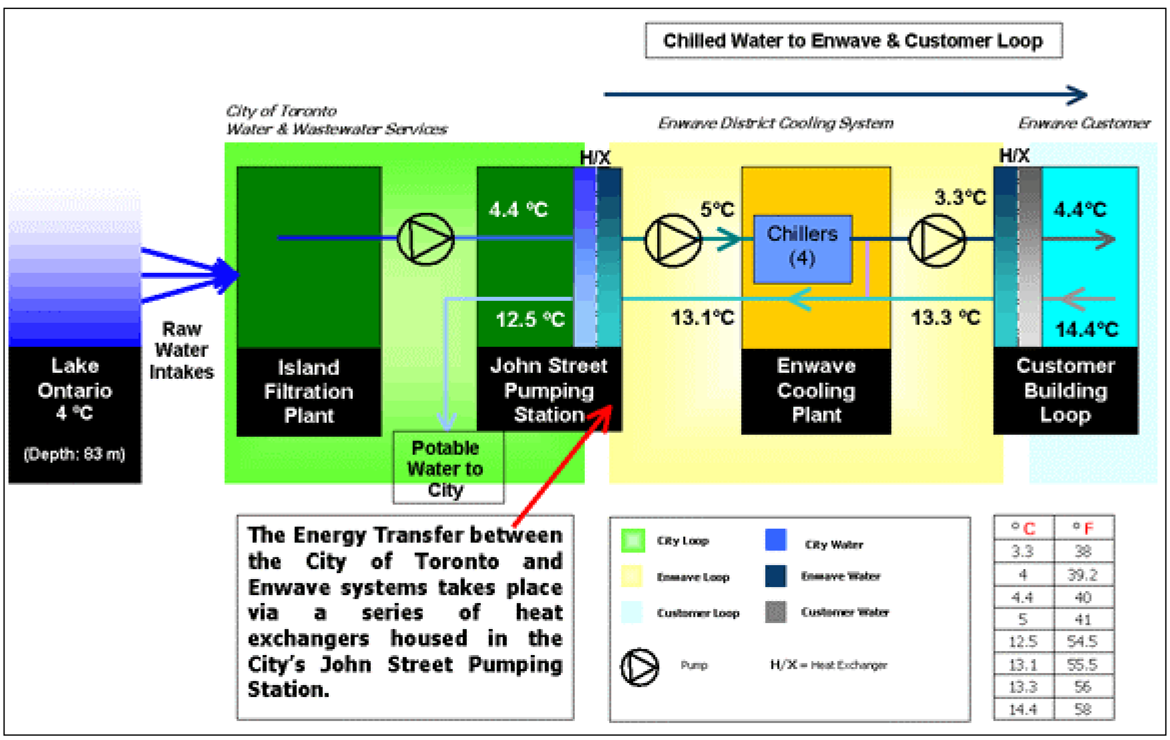


Figure 3: Schematic demonstrating heat transfer of Deep Lake Water Cooling system

COST ANALYSIS

The project cost is approximately $175 million (capital). The initial studies and plant upgrades were accomplished through cost sharing between the City and Enwave. The Green Municipal Funds supported the project with a loan of $10 million over ten years. The remaining construction and the operating costs will be primarily borne by Enwave. The City of Toronto receives revenue through an Energy Transfer Fee based on the amount of cooling energy transferred. In exchange for Enwave's use of Island Filtration Plant a new intake was installed at a value of $55 million at no cost to the City. Enwave doesn't consume any water but borrows coldness. In exchange the City has a stable source of raw water that requires substantially less chemical treatment. This results in a significant operating cost reduction to the City. The start-up funding is in the form of Enwave share capital and debt financing; it is apparent that the investment will generate an acceptable return on equity over 25 years. The intensive capital infusion must be recovered primarily from energy savings realized from the high proportion (over 80 %) of renewable cooling obtained from the system.

The ultimate cooling capacity of 52,000 TR will displace up to about 36 MW of Toronto electrical demand that would have been required to provide that cooling within building plants. The cooling demand usually peaks when the overall electrical demand also peaks, so this reduction is particularly significant.

The energy reduction of the completed plant upgrades is expected to save about 45,000 MWh per year of electrical production, reducing the related environmental impacts. Enwave's owners have requested that detailed costing information not be released.

Other external cost savings, social and environmental benefits include:

- Reduction in greenhouse gas (GHG) emissions by avoidance of fossil fuel generated and imported electricity for cooling.
- Reduction in CFC emissions by replacement of conventional chillers with DLWC.
- Creation of several thousand person-years of local labour to construct the tunnel and distribution system.
- Immediate cost-savings that translate to lower costs of doing business in the downtown.
- Reduction of noise and humidity in the downtown due to DWLC vs. on-site chillers.
- A zebra mussel-free source of drinking water for Toronto and elimination of the need for chlorination at the intake.
- Avoidance of costs associated with the addition of charcoal filtration to address taste problems during late summer.
- Elimination of building cooling towers that require treatment and use large quantities of water.
- Significant reduction in noise levels from cooling towers, improving city liveability and usability of rooftops.

2) EDMONTON'S INTEGRATED WASTE MANAGEMENT SYSTEM, ALBERTA

(Type 1, 4 & 5 Green Integration)

Figure 4: Edmonton's Co-Composting Facility

As the world's population continues to grow and the trend toward urbanization continues, expertise in the areas of municipal solid waste and wastewater treatment is critical. The City of Edmonton, with a population of over 666,000, has implemented a unique and globally recognized solid waste management system. Using this system Edmonton is successfully diverting 60 per cent of residential waste from landfill, more than any other major Canadian city, and continues to increase the rate of diversion through enhancements to the system.

In the early 1980s, when the City-owned landfill was nearing capacity, Edmonton began a search for a new landfill site, which was met with public opposition. Residents made it clear that they did not want a landfill located close to residential areas and demanded a more responsible and sustainable approach to waste disposal that would not compromise their children's quality of life.

City staff seized the opportunity to develop an entirely different approach and assessed long-term strategies that focused on reduction, recycling, and resource recovery as well as alternatives to landfill. The reassessment spawned a 30-year Waste Management Strategic Plan, a holistic approach that would be environmentally sensitive within financial and practical constraints.

Edmonton's Integrated Waste Management System (IWMS) has been developed using a phase-in approach since 1994. The integrated, green components of the system include:

- Extensive public education programs (demand-side management) that foster high rates of recycling, increased diversion of Household Hazardous Waste (HHW), and increased participation in reuse and reduced waste generation. The program also includes school programs, a backyard composting demonstration centre, a waste hotline and a Master Composter/Recycler program.
- A leachate treatment facility that processes up to 10 million litres of leachate per year before sending it to the wastewater treatment plant.
- A Materials Recovery Facility to accept commingled recyclables from the City's blue bag recycling program.

- A Co-composting Facility (Figure 4) that processes 180,000 tonnes of residential waste and up to 22,500 dry tonnes of biosolids from the wastewater treatment facility, producing 80,000 tonnes of compost. The compost meets stringent federal and provincial standards for compost quality and is then sold for agricultural and soil remediation uses.
- The Gore composting system that enables the city to compost additional biosolids from the Gold Bar Wastewater Treatment Plant.
- Methane capture from the City's Clover Bar landfill where methane is collected, cleaned, and converted to electricity, enough to meet the power requirements of 4000 homes and equivalent to removing 44,000 cars from the road.
- Two Eco-stations for the collection of HHW that also serve as transfer stations for all types of HHW.
- A new agreement with GEKO Recycling Technologies Inc. from Germany to construct an electronics and metals recycling plant.
- A multi-family recycling program that includes depots and direct collection.
- The development of a Centre of Excellence in waste management supported by government, industry, and research partners, as well as two new research facilities, one for solid waste and one for wastewater treatment.

COST ANALYSIS

Edmonton's Waste Management Strategic Plan led to two major public/private partnerships – the $12 million Materials Recovery Plant built by BFI in 1999 and the $100 million Co-composter Facility built by TransAlta in 1999/2000. Recently the centre has attracted more private investment with GEKO Recycling Technologies Inc. taking the lead on constructing a $15 million electronics/metals recycling plant. The Leachate Treatment Plant cost $4.4 million to construct in 1995.

Waste management services are funded through a dual financing system through a combination of taxes and monthly user fees. This approach provides a steady and predictable source of funding that permits long-term planning and capital financing opportunities beyond the limited municipal financing sources. Annual increases in the cost of waste services per household are in keeping with the waste management financing plan to achieve sustaining levels with Consumer Price Index (CPI) % increases by 2007.

Additional costs include minor increases in full-time staff positions as most of the operations are contracted out to the private sector. Other funding sources have included the Green Municipal Funds, which helped support the feasibility study of the gasification plant. The Canada/Alberta Infrastructure Program supported the construction of the $8.4 million research facilities. Outside of these initiatives the city has not received any other financial contributions from government. The public/private partnerships were essential.

Other external cost savings, social and environmental benefits include:

- Significant cost savings from avoided landfill construction and expansions,

- Reduced displacement of raw resources,
- Gains from avoided negative real estate values associated with landfill, and
- Avoided losses of productive land.

3) VANCOUVER/DELTA GAS COLLECTION AND UTILIZATION PROJECT, BRITISH COLUMBIA

(Type 3, 4 & 8 Green Integration)

Figure 6: Delta Greenhouse Cogeneration Facility

The City of Vancouver and the Corporation of Delta, with a combined population of 650,000, have entered into a project that expands their current Landfill Gas (LFG) collection and flare system to 156 wells and brings in a private partner, Maxim Power Corporation, to make “beneficial use” of the LFG. Under the Landfill’s Operational Certificate (B.C. Ministry of Water, Land, and Air Protection), Vancouver has an obligation to manage landfill gas from the Vancouver landfill (located in Delta). The operational certificate strongly encourages movement towards “beneficial use” of LFG. The City of Vancouver, adopted the Clouds of Change program in 1990 committing to achieve a 20% reduction in carbon dioxide emissions by 2005 compared to 1988 levels. Landfill gas comprises 5% of Canada’s Greenhouse Gases (GHG).

The basis of the project was to find a community partner who would beneficially use the LFG. The beneficial use contract involves a 20-year agreement between the City and Maxim Power Corp. to construct a 2.5-kilometre pipeline to link the LFG system to a cogeneration facility located at large-scale tomato greenhouse operation in Delta, owned by CanAgro Produce Ltd. The electricity generated at the cogeneration plant is sold to BC Hydro under its green energy program. The heat is used in the form of hot water in the greenhouse, reducing CanGro’s use of fossil fuels by 20%. Low-cost heat also supports the creation of 300 greenhouse jobs.

The majority of LFG collected at the expanded landfill would otherwise be flared to control odours and greenhouse gas emissions. Previously, approximately three percent of the collected LFG was used to provide heat and hot water for the landfill’s administration building. Based on the current rate of LFG collected and flared, approximately 500,000 GJ of energy per year is available for utilization. This amount of energy is equivalent to serving annual energy requirements for approximately 3000 to 4000 homes.

COST ANALYSIS

The total cost of the project is approximately $10 million, invested by Maxim Power Corp. The Green Municipal Funds supported the project through a multi-million dollar loan as part of the financing. The initial projected revenues to the city for providing the LFG fuel source to Maxim were expected in the order of $250,000 to 300,000 per year, which would help to offset the costs of operating the landfill. However, since the LFG system has been in operation, the City of Vancouver has seen higher than expected revenues in the order of $400,000 per year. Since the annual cost of operating the LFG control system is approximately $250,000, this means that the revenues more than offset the costs to the municipality. In addition, Delta expects to receive between $80 and $110,000 per year in municipal tax revenue.

Other external cost savings, social and environmental benefits include:

- Reduction in greenhouse gas emissions of approximately 200,000 tonnes per year of carbon dioxide equivalents, similar to removing 40,000 automobiles from the road,
- Cogeneration provides a larger community benefit through working with the greenhouse to lower their energy costs,
- Cogeneration can recover up to 85% of available energy, much more efficient than simply electrical generation, and
- The electricity generated at the cogeneration plant will produce over 46GJ of electrical energy per year to the power grid, equalling supply for 7000 homes.

4) HAINES JUNCTION GEOTHERMAL DISTRICT HEATING, YUKON (Type 6,7 & 8 Green Integration)

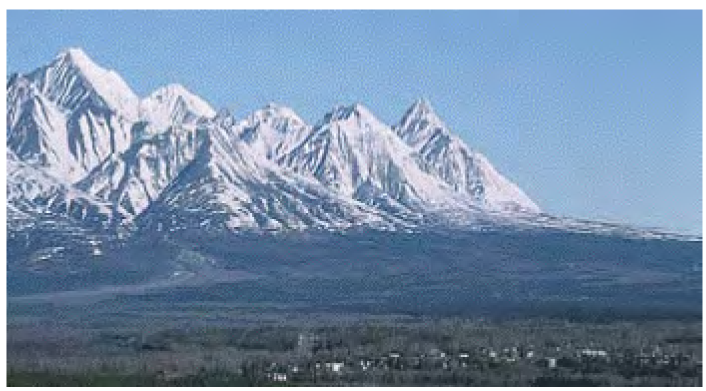


Figure 7: Haines Junction community

Haines Junction is a small, remote community with a population of roughly 800, located in Shakwak Valley in southwester Yukon (Figure 7). Yukoners are high intensity energy consumers. While most of the Yukon's electrical generation requirements are being met through renewable resources (hydro and wind), which do not emit greenhouse gases, the colder winter temperatures and shorter days, associated with the northern latitudes, translate into a higher per-capita energy demand (for space-heating and lighting). Currently the majority of the village's heating systems are based on heating oil.

Haines Junctions' water supply comes from wells and deep aquifers fed by glacial deposits on the foothills of the Auriol Range. The process of drilling a new well to meet the community's water demand, led to the discovery of a warm-water artesian aquifer at a depth of approximately 850 feet. The well not only supplies potable water, but also provides heat, bringing forth water at 16.6 degrees Celsius. The village has entered into a joint venture with the Energy Solution Centre to determine the feasibility of using the natural heat to supply a district heating system. The project has the potential to remove the entire community of Haines Junction from dependence on fossil fuels by utilizing geothermal technology to meet energy needs. Studies show that 55kW of heat is available from the first well studied.

The initial stage of implementation will permit the village to match the volume of heating water to the current rate of domestic water consumption. Studies have confirmed the use of well water for heat extraction and distribution to the core village building heating systems (convention centre, school, and arena) using geothermal heat-pumps. Supplying the entire village with geothermal heating may be possible depending on the volume of water available. This will require re-injecting the excess water not used by the community back to the aquifer to maintain water volumes and reduce waste. The volume of water required for heating will exceed domestic water consumption. Therefore, a second well will be required for re-injection with added pumping requirements along with a system to de-chlorinate the returned water.

COST ANALYSIS

The community of Haines Junction will be forming a utility where it will be selling heat at a percentage of the avoided cost. Under this scenario, the utility costs are expected to be in the order of 50% of avoided costs (from space heating) and the customer costs may be up to 75% (TBD) resulting in a net yield of avoided costs to the village. The utility will retire debt and early models show a return on investment of just below 10%. The consumer will save 25% with no investment and all parties will benefit. A significant reduction in negative environmental impact will result from the greenhouse gas reductions. The business plan for the project is underway; therefore, all figures are estimates only. The Green Municipal Funds supported the initial feasibility study for the project.

Other external cost savings, social, and environmental benefits include:

- A reduction of the current use of fossil fuels by approximately 90%,
- A similar reduction in greenhouse gas emissions, attributable to its burning and transportation,
- An expected increase in tourist to this “green community” and
- A reliable and constant supply of “price and shock resistant”, affordable heat.

5) INTERNATIONAL EXAMPLES: ACHIEVING HIGHER LEVELS OF INTEGRATION

Hammarby Sjostad's Waste to Energy and Fertilizer in Stockholm, Sweden

Hammarby Sjostad is a district with a growing population of 20,000. Source-separated organics (food waste) are conveyed from residences and restaurants to the Henriksdal Wastewater Treatment Plant along with wastewater (Figure 8). Currently, the Plant is undergoing four separate pilot projects to determine the most environmentally appropriate method of processing the organic wastes. In one scenario, the organics undergo anaerobic digestion producing biogas (methane), which is delivered back to the source residences for heating and cooking, with future plans to fuel vehicles. Various technologies are being tested that extract nutrients from the sludge to be spread on farmland or contribute to compost. Heavy metals and other hazardous compounds are dealt with primarily at source through public education.

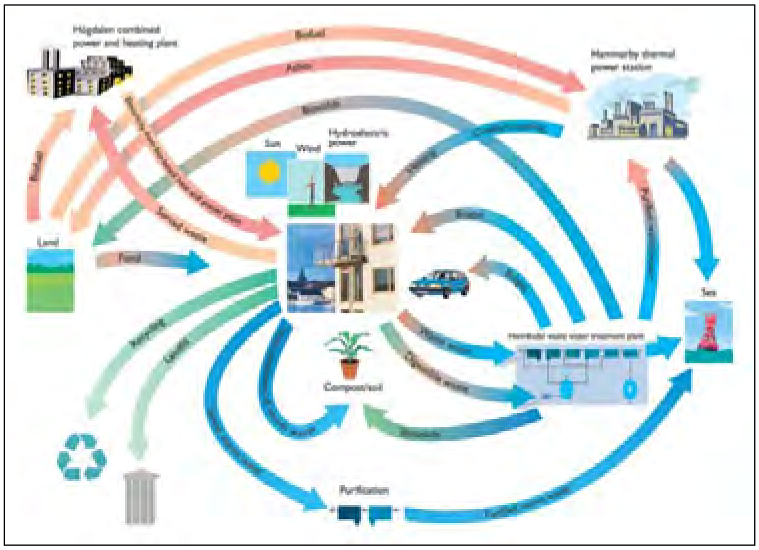


Figure 8: Hammarby Model

BedZED's Integrated Water Management in South London, England

BedZED's wastewater is treated on-site by a Living Machine located in a greenhouse. In this bioregenerative system, nutrients are extracted by plants and other organisms transforming it into "greenwater." Greenwater is stored along with green roof runoff in underground tanks for irrigation and toilet flushing (Figure 9). Unused non-potable water drains into a dry ditch along with parking lot and road runoff creating a water feature specially designed to attract wildlife. The existing public sewer is only used in case of emergency.

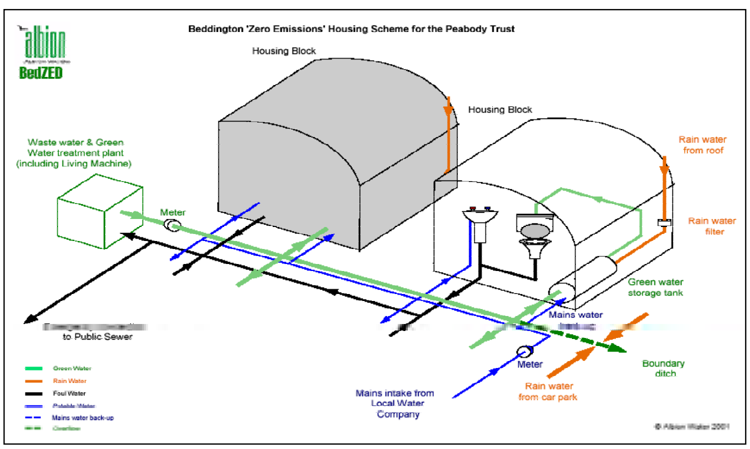


Figure 9: BedZED Integrated Water Management

Water efficiency is further increased on the demand side, with water efficient appliances and fixtures, highly-visible water meters, and a handbook for every household with tips on reducing water use. As of 1989, water supply and wastewater treatment in London is privatized. Although specific costs are not yet available, it is appears that this Integrated Management System is an economically preferable solution.

STAGE 2 RESULTS: "THEORETICAL" DEMONSTRATIONS

Full community development presents possibilities to implement comprehensive, green infrastructure integration that may otherwise be less feasible. Optimal integrations and opportunities for green infrastructure are revealed through the holistic examination of key issue areas such as water, energy, waste, materials and site in terms of setting both environmental and social objectives. Such opportunities cut across building, site and infrastructure issues, naturally leading to the identification of synergies. This is the approach that has been taken here in order to develop the theoretical scenario and its three clusters of synergies. Our scenario is based on a real-world redevelopment site for which the Federation of Canadian Municipalities participated in a sustainable design workshop to generate ideas among experts, to inform the redevelopment process. The myriad of complex concepts and ideas generated have been described as three separate clusters that offer strong synergies among infrastructure components, provide leading edge ecological design opportunities and present opportunities for strong cost off-sets.

COSTING METHODOLOGY

A spreadsheet was created to compare Base Case costs to Optimal Case costs. We prepared a detailed list of items to be costed within each scenario. Where practical, infrastructure components and related elements were costed by incremental premium rather than attempting a time-consuming full capital cost estimate. For example, in the energy analysis, we did not estimate the costs of building over 4500 housing units. Instead, we estimated the costs of upgrades that differ from the other scenario. The bottom line, expressed here as a 10-year cost, does not lose accuracy by this method.

The "life-cycle analysis" includes considerations of replacement costs for items and equipment over a period of 75 years. To determine the 10-year costs for our scenarios, we quantify the annual operational and maintenance costs, annual energy costs and annual replacement reserve. The sum of these numbers, multiplied by ten years, gives the 10-year cost of implementation. To compare the two scenarios, the Base Case costs are subtracted from the Optimal Case costs, so a negative number indicates a savings for the Optimal Case scenario. The complete spreadsheet has been attached as Appendix A.

The annual replacement reserve financing is calculated as an annual amortization cost of the replacement cost determined by the life span of the item. An interest rate of 3% is used.

Life spans (LS in spreadsheet) were assigned to each item costed. For example, the following values were used in the energy cost analysis:

In-suite mechanical systems	25 years
Windows	30 years
Central plant equipment	25 years
Building envelopes	75 years

CASE STUDY SET-UP

The base case study developed may contain similarities to the real-world development on which it is based. The proposed design solutions are fictional at this stage but are actual extensions of what has been developed in Canada and abroad to date and may warrant application on the basis of these findings. The presumptions that inform the cost analysis for this site are outlined as follows:

- The scenario under consideration represents a unique urban redevelopment project or urban infill within a large North American metropolis. The area to be redeveloped is within a reasonable proximity of the downtown core and the central business district. The size of the redevelopment is 28 ha of existing, fully serviced, residential land. The site is regularly shaped and bounded by major arterial roads to the north, west, and east, with the main street bisecting the site into major north and south blocks.

- The existing infrastructure and buildings were constructed in the post-war era (following 1945). The number of mixed-income residential units to be built on the site is approximately 4500 with 75% of the units accommodated in apartment buildings and the remaining in townhouses or stacked townhouses. The density of the redevelopment is averaged at 160 units/ha.

- The redevelopment plan is characterized by an interwoven street and block pattern laced with linear parks and parkettes. Twelve similar blocks, each around 2 hectares, will hold 3700 apartment units and 880 townhouse units. The neighbourhood blocks surround a central park feature (approximately 2.5 hectares). Mixed uses (retail, commercial, and institutional) are integral to the buildings facing the central park area and along main streets. Estimates include 23,000m^2 of space for retail, commercial, community, and educational uses on-site. Setbacks from the roads are minimal to encourage lively streets and community interaction.

The base case for the existing traditional infrastructure approach is outlined generally as:

Energy Servicing

- Townhouses have their own gas heating and hot water systems.
- Apartments have unit heat pumps supplied with gas-fired boilers and cooling towers.

Buried Infrastructure

- Combined storm and sanitary sewers are rebuilt as separate.
- Private servicing (hydro, television, telephone, fibre optic).

- Sized to accommodate population projections.

Transportation

- Two-way streets at 18m ROW with on-street parking along one side.
- Linear parks are featured along some major streets.
- Smaller streets are one-way at 15m ROW including traffic lane and on-street parking.

The following descriptions depict the three optimal synergies of green integration we identified, followed by the economic analysis. Each synergy cluster is described and costed with the assumption that the other two are implemented. The scenario has been divided into three clusters for ease in description and to facilitate costing.

CLUSTER A: TRANSPORTATION AND CONVEYANCE

DESCRIPTION

This synergy integrates transportation infrastructure with conveyance infrastructure while increasing opportunities for surface greening. The redevelopment density requires most of the parking to be below grade and, if restricted to the building footprints, would require multiple levels, with consequent high costs. In the traditional approach, the provisions for the transportation and conveyance of materials, water and people are the responsibility of several separate departments of a municipality requiring coordination. Roads constitute the primary infrastructure to serve a variety of needs including people movement (pedestrian, cyclist, public transit, and cars), as well as shipping, service and emergency vehicle access. Infrastructure for water, sewage, gas, stormwater, electricity and communications conveyance are typically buried or above roadways and easements. Parking is either a municipal requirement for development, or directly owned. Municipal vehicles are required to maintain the roads or provide other services.

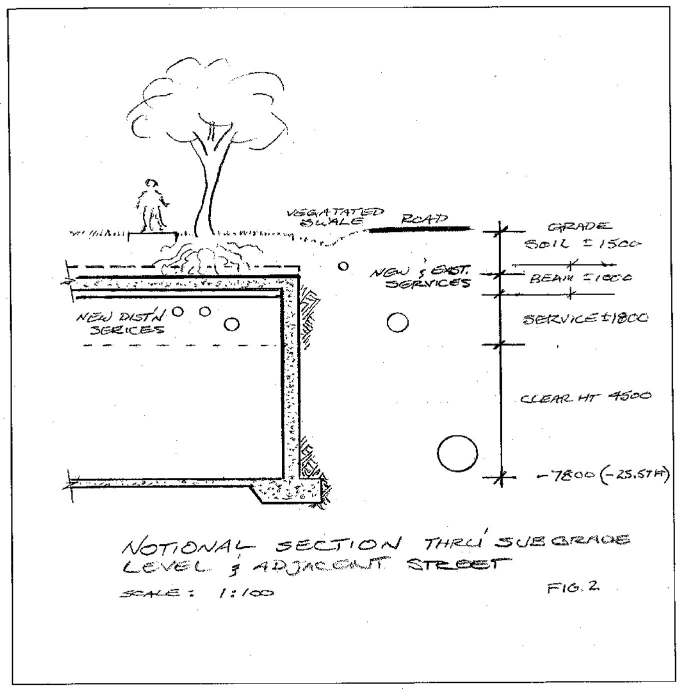


Figure 10: Cross-section of below-grade service level

An integrated, green infrastructure approach is to construct a five-metre high, single storey, below-grade service level across the whole site with the exception of major roads, parks and retained significant buildings, to accommodate a broad set of cost-saving and beneficial provisions. The landscape at ground level will function much like a green roof. Located within this concourse level will be parking for cars and bicycles, pedestrian walkways, retail, and other amenities. Infrastructure conduits, which are typically buried, are in this case hung from the ceiling (Figure 10). Autoshare-type programs and shared parking will reduce the amount of parking required per unit to approximately 50%.

Another major component of this synergy includes the handling of municipal solid waste through a new and innovative European technology known as the piped vacuum collection system. Whereas the traditional infrastructure approach involves household garbage pickup, separation, and landfill costs, this scenario allows household waste to be sorted at source. Separate waste streams are conveyed to storage locations in vacuum chutes running through the below grade service level to a central, underground location for pickup. Recyclables and non-organic waste are picked up from the storage location by the municipality. Organics are conveyed directly to anaerobic digestion tanks situated throughout the site.

SYNERGIES

The synergies addressed by these green integrations include:

1. Maximizing stormwater infiltration and surface greenspace or urban agriculture while reducing surface pavement to minimize heat island effect and to enhance biodiversity.
2. *Combined municipal service distribution and local energy supply lines located in the overhead service zone. Infrastructure conduits are run in ceilings (hung) for ease of servicing and maintenance access.
3. *Each major parcel of building development defined by the major street grid is fully excavated to accommodate parking requirements rather than individual building footprints that will entail multiple levels.
4. *A pedestrian pathway system with tunnel connections across the major streets provides sheltered access to commercial, community and public transit facilities. Non-vehicular local transportation, e.g. walking, or bicycling is enhanced by weather protection provided by enclosed routes, particularly during inclement weather.
5. *Truck pickup is limited to central collection locations with the piped vacuum collection system for separated municipal solid waste.
6. District energy distribution, water recovery and water reuse facilities would ideally be located in a below grade accessible space.

***Starred elements have been costed in this scenario.**

These synergies coalesce in the concept of the below grade active service level. Major street ROW's are retained, along with their buried services. Vehicle tunnels are located strategically to minimize impacts to existing services. Pedestrian tunnels can be located under most street ROW's. The areas identified for service uses should be sufficient for parking, delivery routes and unloading bays. It is also conceived that many skylights, light wells and stairwells would closely tie the surface activity to this sub-grade level.

COST ANALYSIS

Infrastructure Cost Component	Base Case ($)	Optimal Case($)
Underground Parking	$55,000,000	$51,100,000
Municipal Solid Waste	$22,300,000	$14,100,000
Service Infrastructure	$12,700,000	$7,940,000
10-year Total	$90,000,000	$73,100,000

COST OFFSETS

The transportation and conveyance cluster accommodates pedestrians, vehicles, bicycles, and retail opportunities while allowing for the maintenance of municipal service and energy distribution that normally would involve costly, above-ground disturbance and inconvenience to residents. Savings achieved directly through building a single 5-metre high, below-grade service level are minimal in comparison to the cost of multi-level underground parking limited to the building footprint.

An interconnected multi-purposed concourse level would reduce capital costs in several ways. Piping and wiring placement is considerably less costly than buried installation. Above grade roads, parking, and stormwater requirements are reduced. Facilities that would otherwise require dedicated land use and separate conditioned structures are less expensively sited in the concourse. There are also sizable operating and maintenance cost savings attributable to this approach.

The below-grade service level increases the practicality and financial feasibility of the piped vacuum collection system for separated municipal solid waste by allowing for easy access of maintenance as well as providing central collection locations. This approach not only reduces costs pertaining to garbage pickup but limits vehicular site activity to mainly emergency uses affecting a variety of typical surface road design costs and opening up the opportunity for pervious paving for emergency routes. The high maintenance costs of the conventional system are more than offset by the low operation and maintenance cost of the vacuum waste collection system, despite the high capital costs.

OTHER EXTERNAL COST SAVINGS, ENVIRONMENTAL AND SOCIAL BENEFITS

- Provisions of space for district energy centres, stormwater cisterns, and components of wastewater treatment could be strategically located in the below grade service level to suit a phased development – underscoring the flexibility of the service level concept (described further in the next two clusters).

- Reduced roads and automobile servicing leaves more opportunity for pedestrian and bicycle paths.
- Greenhouses for wastewater treatment integrated with lightwell entries into the service level may also serve for public spaces and horticultural production.
- Facilities for enterprise and commercial activities would contribute to local employment opportunities. These may be oriented to green production, goods, and services such as reuse/repair and healthy food-processing.
- Live/work accommodations and small shops along major streets will serve some of these functions. Larger production facilities could be located below grade.
- A much greater area of greenspace and car-free public space is made available on the surface using this approach.
- On-site stormwater management is facilitated with reduced pavement.
- Paved surfaces for solid waste pick-up, surface parking, and service vehicle access are accommodated in the below grade service level, reducing snow removal by leaving more open space available for on-site snow retention, eliminating the need to transport snow off-site.
- Snow removal and salting is reduced, lessening negative impact on the natural environment.
- Reduced traffic flow improves air quality, reduces noise, and results in safer conditions.
- Public safety and security would be reinforced by existence of mixed amenities and by parking surveillance and control garage entry.
- Priority locations would be given to shared automobiles, rentals, bicycles, and other designations that reduce parking demand and car usage.
- Municipalities gain revenue as the parking authority and through reduced above-ground development.
- Pathway system that can be enhanced by skylights, open stairwells, moving sidewalks, bus shelter nodes and features similar to malls as in a typical underground pathway system.

CLUSTER B: WATER, WASTEWATER, STORMWATER

DESCRIPTION

This scenario is designed to maximize stormwater infiltration across the site, recycle, and cascade water on-site, and combined with water efficiency measures, provides an optimum integration. The traditional infrastructure approach involves: separated wastewater and stormwater sewers to city trunks and centralized treatment facilities; impervious paving for all roads, sidewalks, and pathways; roof drains to storm sewers; potable water connections from existing pipes in major streets and; surface irrigation using potable water. Today's approach to addressing stormwater is primarily aimed at managing runoff and flow volumes during storm events in paved urban areas with some attention to treating water quality prior to discharging into rivers and lakes.

Figure 12: Urban green rooftop

In the integrated, green infrastructure approach, the landscape is designed for reduced irrigation needs and vegetation cover is targeted at 300mm over all open space except on streets. This is a significant increase in permeability over business as usual. A layer of soil with a minimum thickness of 1.5m will span the site. An extensive tree canopy, permeable paving on secondary road and walkways, street biofiltration drains, swale infiltration verges and tree trenches with draining paving will contribute to on-site stormwater management. Water not retained and evapotranspired by soil and vegetation will be conveyed to stormwater cisterns, which is only expected to occur during major storm events. Flat rooftops with vegetation (Figure 12) retain and evapotranspire water, whereas, runoff from slanted roofs will be treated to non-potable standards and stored in underground cisterns. Non-potable water will be used for irrigation, toilet-flushing and other non-potable uses such as washing of vehicles. Excess cistern water will be infiltrated to allow replenishing of groundwater (if permeability of soil permits). The goal is to reuse or infiltrate all stormwater on-site and eliminate the need for storm sewers.

Figure 13: Bioregeneration of wastewater in greenhouse

The second major component of this cluster, water cascading, refers to matching end uses of recycled water in varying degrees of cleanliness. Greywater from washing is plumber separately and heat is recovered to preheat domestic hot water. The greywater will then be treated through bioregeneration (Figure 13) and stored in cisterns for non-potable reuse. Blackwater is conveyed to anaerobic digestion tanks in semi-central locations (one or two facilities per block), or a central anaerobic digestion facility. Resulting leachate will undergo treatment in ecological restoration tanks, similar to greywater. So, in the cooler months, the same water can be used for washing, heating, and toilet-flushing before being re-treated and infiltrated to rejoin the hydrological cycle as groundwater.

The last major component, water efficiency, is optimized using site-wide demand-side management (DSM). This includes water efficient fixtures, metered potable water usage, and water efficient toilets (i.e. dual flush, ultra-low flush, or urine-separating toilets). Urine from urine-separating toilets will be stabilized, treated and sold to farmers to fertilize fields. Demand-side management, together with water cascading, is expected to reduce potable water consumption by about 60%.

SYNERGIES

The synergies addressed by this cluster of servicing include:

1. Stormwater collection to common cisterns for 12 blocks, connected to non-green roofs and garage decks, (green roofs implemented wherever possible) all towards reduced stormwater discharge and increase natural recharge.
2. Rainwater filtration and disinfection with pumping and distribution to flush water supply and groundwater recharge bed in park.
3. Permeable paving for all but major streets, road runoff to swales, infiltration basins and retention/infiltration tanks for each phase and subsurface irrigation.
4. Water conserving fixtures and appliances; separated greywater, urine and black water (faecal flush) plumbing; and separate non-potable flush water supply to reduce potable water use and recover nutrients.
5. Blackwater anaerobic digester (septic) tanks for each building block along with treatment facilities for greywater and leachate from septic tanks with a tertiary-level ecological greenhouse system.
6. Potable water supply from existing street mains.

*** All elements are included in the cost analysis for this scenario.**

These synergies coalesce in the concept of a closed loop water recycling system. Water resources are most efficiently utilized through a decentralized treatment and capture system and reused according to their most appropriate end uses. This approach minimizes infrastructure spending on pipes but requires increased sophistication in decentralized treatment and capture systems. Other benefits include increased infiltration (snow retention and storage) through permeable pavement, reduced treatment costs through natural biofiltration processes and reduced heat island effect. The approach is very localized making the system more resistant to perturbations.

COST ANALYSIS

Infrastructure Cost Component	Base Case	Optimal Case
Water Supply	$25,900,000	$9,000,000
Water Treatment	$26,200,000	$34,200,000
Stormwater	$400,000	$2,400,000
Landscaping and Paving	$15,500,000	$16,500,000
10-year Total	$68,000,000	$62,100,000

COST OFFSETS

The savings in potable water usage achieved by site-wide water reuse and recycling, on-site wastewater treatment and on-site infiltration offset the costs of optimizing stormwater management, landscaping and the costs of decentralized, on-site treatment facilities.

Landscaping costs do not differ significantly between the two scenarios. The bulk of the savings is achieved through the 60% potable water reduction, which reduces both capital and operating costs. These savings are attributed to the implementation of water saving and reusing features as well as the decentralized stormwater and wastewater treatment systems.

Savings earned through demand-side management approaches offset costs to incorporate dual flush and urine separating toilets and shared greywater treatment, anaerobic digester tanks, and cisterns. Although not evident in the cost analysis of this cluster, the capital costs of greywater heat recovery significantly reduce energy load, the benefits of which are expressed in the cost analysis of Cluster C.

OTHER EXTERNAL COST SAVINGS, ENVIRONMENTAL AND SOCIAL BENEFITS

- A 60% reduction in potable water use.
- Elimination or reduction in stormwater discharge and/or improved water quality.
- Elimination or reduction in wastewater flow.
- Reduction in wastewater treatment requirements and sludge disposal.
- Reduction in greenhouse gas emissions through anaerobic digestion and biogas capture.
- Recovery of nutrients for agricultural uses.
- Increased site vegetation, greening of communities, and biodiversity.
- Reduced heat island effect.

CLUSTER C: ENERGY INTEGRATION

DESCRIPTION

The goal of this cluster is to minimize site-wide energy use and net greenhouse gas production resulting from the site's activities. Traditional energy utility services, including natural gas and electricity, serve to supply space heating, space cooling, and electrical end uses in buildings. Residential developments, consisting of townhouse blocks and multi-storey apartment buildings, would conventionally be developed under the current Ontario Building Code (OBC) requirements for thermal envelopes to include: modest insulation levels, double glazed windows, no specific attention to airtightness performance and significant thermal or cold bridging. Ventilation, though continuous, is of questionable efficacy and constitutes a significant winter heating requirement and summer moisture loading, requiring dehumidification. In-suite lights and appliances would be of conventional efficiencies. Thermal space conditioning requires significant electricity for fan power and utilizes mid-efficiency natural gas heating and electric cooling systems located individually at each townhouse suite or centrally at each apartment building.

The integrated, green infrastructure approach suggests a 2.0 MW gas turbine generator and recovered heat boiler work in conjunction with a central heat pump, 3000m^2 of solar thermal collectors to preheat water for cogeneration plant, as well as active and geothermal storage systems. The system will be run to operate to meet thermal requirements for the community, producing electricity in the process. The electricity produced would be enough to operate the plant, heat pumps and the hot and coldwater distribution system. The rest of the site power, approximately 20.5 GWh per year, is purchased from the power grid for on-site use. An on-site wind turbine, biogas and/or photovoltaics may be considered as a future possibility when the increasing costs of fossil fuel-based energy production meet and exceed the costs of renewable energy.

Additional building-scale energy efficiency features include:

- A high-performance building envelope with higher levels of insulation and window thermal performance, increased airtightness and avoidance of thermal bridges.
- Effective balanced ventilation systems with exhaust air energy recovery, augmented with ground preheat.
- High efficiency electric appliances and light fixtures with compensating controls.
- Significantly reduced mechanical and electrical capacity requirements for the same end uses
- A district thermal energy system for supplying hot water for winter space heating and year-round domestic hot water supply and summer chilled water.
- In-suite distribution is from cast-in-place radiant ceiling pipe grids, to deliver heating and cooling, avoiding dedicated townhouse or apartment building heating and cooling equipment and supply temperatures of 18 degrees C. cooling and 28 degrees C. heating.

SYNERGIES

The synergies addressed by this cluster of energy end uses and alternative supply systems, that may result in municipal capital, operating and life-cycle cost savings while improving environmental performance, include:

1. A system concept that maximizes on-site HVAC energy services with a high degree of efficiency and use of renewable energy.
2. Efficiencies in building design to reduce energy loads on the central cogeneration system and building level equipment transferred to the central plant.
3. A central cogeneration heating and cooling plant with active ground source thermal storage.
4. System integrations using conventional energy and renewable energy sources with both active and geothermal thermal storage to obtain maximum utilization of the available plant capacity.
5. Use of the generator to generate heat that is recovered as a power bi-product.

6. Electricity produced through cogeneration is enough to run district energy system, giving it the ability to provide heating and cooling in the absence of grid power as well as emergency power supply.

These synergies coalesce in the concept of a cascaded energy system. This system concept was structured to supply on-site HVAC and domestic water heating energy services with a high degree of utilization, and use of renewable energy. For example, the heating supply serves domestic hot water first, and then is cascaded for space heating duty.

COST ANALYSIS

Infrastructure Cost Component	Base Case	Optimal Case
Envelope + Construction	base	2,100,000
HVAC	19,300,000	12,000,000
Electric	base	800,000
Heating + Cooling Supply	2,600,000	15,600,000
Operation + Maintenance	104,500,000	55,000,000
10-year Total	126,400,000	85,500,000

COST OFFSETS

The cost analysis of the energy integration cluster shows a 10-year net cost saving of $41 million (difference between base and optimal) in favour of the Optimal Case scenario. These savings can be expected to increase over time while the effect of initial central plant costs diminish and the energy cost escalation increases.

The energy costs were taken as the average over the next 10 years, estimated at $0.17 per kWh for electricity and $0.0774 per kWh for gas. The capital cost increases to Envelope, Construction and Electrical upgrades are easily offset by energy cost savings. The reduced costs of HVAC systems at the building level in the Optimal Case scenario are as a result of the district energy, cogeneration system. Over the 10-year pay period considered in this cost analysis, the capital costs of the district energy system are offset more than threefold by the cost savings of energy costs.

OTHER EXTERNAL COST SAVINGS, ENVIRONMENTAL AND SOCIAL BENEFITS

- Reduction in overall energy consumption and increase in overall energy conversion efficiency related to electricity production compared to off-site large-scale generation.
- **A 47% estimated reduction in greenhouse gas (GHG) emissions from reduced energy consumption and increased energy conversion efficiency, equated at $374,500 per year, and $37.4 million over a 10-year period. These figures are suggested as additional savings, over

and above the energy savings estimate of $41 million over 10 years. These savings could be further improved by displacing some or all natural gas with biogas as the fuel source for the cogeneration plant and/or by adding a wind turbine to reduce or eliminate power purchase from the grid.

- The ability to supply heating and cooling to the site despite power outage is of great benefit to the residents, especially in winter.
- The cogeneration plant has the ability to curb peak energy demand, which has the benefits of reducing energy costs as well as relieving the municipal distribution system at peak load times.
- As well, the cogeneration plant enables the housing project to respond to market signals further adding affordability of district energy supply.

** The GHG calculation is based on a value of $25 per tonne on-site energy use (gas and electric) where GHG emissions are estimated at 200 tonnes per GWh for gas and 700 tonnes per GWh for electric.

THE CASE FOR INTEGRATED AND GREEN INFRASTRUCTURE

The purpose of the study is to demonstrate and examine the proposition of integrated and green infrastructure both in terms of “real world” and “theoretical” examples. As we look across the country it is apparent that Canadian municipalities have discovered integrated and green infrastructure approaches, that is infrastructure that adopts ecological engineering and looks for design and financial synergies. Canada offers some excellent examples of Integrated Waste Management Systems for example as shown by the Edmonton case study, and Halifax and Charlottetown provide other leading examples in the areas of energy from waste and IWMS. Edmonton has set out to be a world leader through linking ecological technologies with social amenities in adding research and community education and participation components to their system.

The primary enabling strategy in all of the “real-world” case studies, to embark on integrated and green approaches, is the public/private partnership. In the cases of Toronto’s Deep Lake Water Cooling project, Edmonton’s IWMS and Vancouver’s Landfill Gas project the propositions were possible and lucrative for the municipality due to private investment and innovation. Municipalities make ideal partners for business because they instil confidence in investment making project financing possible. These municipalities were both responsive to or drivers of innovation and adapted their policy provisions accordingly. In fact, all of the case studies showed a lucrative proposition for municipalities since the majority of costs were borne through the private investments and came with agreements for a proportion of revenue resulting from the endeavour e.g. Toronto receives a energy transfer fee and Vancouver receives revenue for methane fuel while Delta receives tax revenue from the cogeneration plant.

In Haines’s Junction, a remote community, the municipality needs to ensure that its’ energy source is resistant to disruptions. The community has relied on imported heating oil and has very high levels of energy use due to climatic factors in the Yukon, which also puts the community at risk in the case of disruptions (e.g. to the electricity grid, importing of oil, extreme weather events). Thus the local geothermal energy provides an optimal solution because the energy source is local, renewable, economical, non-polluting and helps the community be resilient. In fact they may move off-grid completely in future. Both the cold temperatures of Lake Ontario and the geothermal heat source are examples of passive functioning where we make efficient use of services from nature without exploiting non-renewable resources and by matching their characteristics to end-uses. In Toronto, cooling is borrowed from Lake Ontario in a very resource-efficient fashion that ensures water is used for potable purposes or returned to Lake Ontario. A similar approach will be used in Haines's Junction with the use of heat, potable water and returned water to the aquifer. Edmonton and Vancouver/Delta also illustrate high levels of resource efficiency by transforming waste bi-products to secondary resources.

The "theoretical" case studies illustrate the possibilities and leaps that can be taken in integrated and green infrastructure approaches. In Cluster A, the Below Ground Active Service Level completely reconfigures the notion of servicing to examine the synergies resulting from below ground parking and servicing. The approach emphasizes improved uses of valuable land by relocating parking below ground, improving stormwater recharge above ground and increasing service access to buried infrastructure. Additional benefits include the social amenities associated with a secure underground walkway system, retail, and community services already common in Canadian cities. The cost analysis shows that achieving this high level of integration among what are today costly municipal service functions, can be developed at an improved cost over business as usual, over 10 years, and with advanced indirect benefits for the environment and community.

The second cluster, B, examines the cost benefits of a high degree of stormwater infiltration across the site, treating and capturing this non-potable water in underground cisterns to reutilize it for toilet flushing, irrigation and other such uses. The green technologies are combined with demand-side management approaches. Demand-side management (DSM) is a concept discussed at the beginning of this report and one that appears to be underutilized in the "real world" case examples. By underutilized we suggest that while most municipalities have conservation programs in place, they are voluntary, under-funded and generally compartmentalized both in terms of city departments and issues and in terms of being imbedded in infrastructure development. This cluster illustrates the types of linkages that must be made between hard infrastructure and conservation programs to be sustainable and cost effective. Approaches that embed DSM with infrastructure design illustrate community receptiveness to and understanding of resource cycling and closed loop systems. Reduction in resource consumption and lifestyle practices, the link between end uses and system configurations, are necessary presumptions to determining systems capacity needs and budget requirements. Cluster B illustrates another break-even example despite the added advancements in green technologies such as permeable paving, lot level cisterns, separated greywater and their higher capital costs. It should also be noted that Clusters A and B could be integrated together across the site to achieve further synergies.

Cluster C dealing with integrated and green community energy shows the greatest cost benefit of all the examinations. The district energy system using a cogeneration facility and renewable energy supply, combined with green building efficiencies, shows a surplus savings in the order of $41 million over 10 years. This figure presumes today's pricing, which will decrease over time as these systems become more readily applied further increasing the savings. Non-monetized benefits include significant greenhouse gas reductions and greater resiliency from disruptions since district energy is distributed and networked.

In conclusion, the results of this research demonstrate that integrated and green infrastructure has the potential to transform municipal infrastructure developments to achieve high economic, social and environmental value-added to Canadian communities. While many challenges lie ahead in determining the optimal in integrated, green solutions and their feasibility, there are a host of other barriers that will have to be addressed to enable municipalities to move forward. These include but are not limited to the need for: interdependent planning and budget process among city departments, taxation and policy reform, revised fee structures, creation and implementation of full cost accounting models and the optimization of public/private partnerships.

We note earlier in the report that integrated green infrastructure can provide "win-win-win" solutions by addressing the triple bottom line. This can only be accomplished through integrated design processes (IDP) that can help foster not only the technical and economic solutions but also the enabling mechanisms required for success. Through the integrated design process, multiple disciplines and city departments are brought together to create interdisciplinary technical solutions and cross-departmental budgets. Through integrated design solutions it is possible to derive novel solutions that lead to less compromises and more synergies.

We began this report suggesting that we would ultimately argue for applying the structure of ecology as "nested integrities" to planning for functional attributes of sustainable communities, cities and regions. The structure of ecology recognizes that healthy ecosystems are diverse, resilient, adaptable and self- perpetuating. Today's infrastructure is centralized, expensive, and designed for a single-purpose. Integrated and green infrastructure provides a diverse, flexible network with shared elements that can be more cost-effective and more responsive to local needs and opportunities and to today's problems. Pollution and climate change are some of the most pressing issues, as are the real municipal needs to address growing population demands on infrastructure and resources, infrastructure decline and maintenance, funding shortfalls and competing interests. This study has shown Canadian municipalities already see the benefits of green integrations, the challenge is to further develop comprehensive technologies and solutions, and funding formulas that work. In many cases more advanced systems are widely accepted in parts of Europe and around the globe, illustrating that integrated green infrastructure is a global movement and one we cannot afford to ignore.

APPENDICES

Appendix A: Costing Table Comparing Base Case Costs vs. Optimal Case Costs Over a Ten-Year Period

Base Case (OBC Standard)	Capital	Annual O & M	LS	Mortgage Factor x10 years	Amortized Capital Cost	10-year Oper + Main Cost	Total 10-year cost	Total by Sub-Cluster	Integrated Green Infrastructure	Capital	Annual O & M	LS	Mortgage Factor x10 years	Amortized Capital Cost	10-year Oper-Main Cost	10-year Total Annual Cost	Total by sub-cluster	Optimal less Base 10-year cost	Total
Transportation and Conveyance									***Transportation and Conveyance***										
Parking, 3 m height, 4200 spots									**Parking, in 5 m high service level, 3570 spots**										
Total Area = 147,000 @ $800/m2	117,600,000		75	0.336679634	39,593,525	0	39,593,525		Total Area = 124,950 m2 @ $1150/m2	143,692,500		75	0.336679634	48,378,338	0	48,378,338		8,784,813	
Average # of levels/depth = 2-3	7,056,000		75	0.336679634	2,375,611	0	2,375,611		1 five-metre level	0		75	0.336679634	0	0	0		-2,375,611	
Parking surveillance/control	2,000,000	750,000	25	0.559382903	1,118,766	7,500,000	8,618,766		Parking surveillance/control add CCTV	400,000	150,000	25	0.559382903	223,753	1,500,000	1,723,753		-6,895,013	
Ramps	13,200,000	0	75	0.336679634	4,444,171	0	4,444,171		Reduced Ramps - 6 total	1,800,000	-60,000	75	0.336679634	606,023	-600,000	6,023		-4,438,148	
Pedestrian access	0	0	75	0.336679634	0	0	0		Pedestrian Access	2,000,000	30,000	75	0.336679634	673,359	300,000	973,359		973,359	
								55,032,073									**51,081,474**		-$3,950,599
MSW collection									**MSW collection**										
No. of storage, docks loads	2,600,000	606,000	75	0.336679634	875,367	6,060,000	6,935,367		Central vacuum system	14,000,000	300,000	75	0.336679634	4,713,515	3,000,000	7,713,515		778,148	
No. of in building chutes	3,700,000	0	30	0.510192593	1,887,713	0	1,887,713		No. of in building chutes = 98	3,700,000	180,000	30	0.510192593	1,887,713	1,800,000	3,687,713		1,800,000	
No. of street receptacles	0		30	0.510192593	0	0	0		No. of street chutes = 30	300,000		30	0.510192593	153,058	0	153,058		153,058	
Door-to-door garbage collection	0	1,350,000			0	13,500,000	13,500,000		Central garbage collection		250,000			0	2,500,000	2,500,000		-11,000,000	
								22,323,080									**14,054,285**		-$8,268,794
Infrastructure									**Infrastructure**										
All infrastructure buried									*Primarily service level routing*										
Water (potable)	2,110,000	135,000	50	0.388654944	820,062	1,350,000	2,170,062		Water (potable)	1,577,000	101,500	50	0.388654944	612,909	1,015,000	1,627,909		-542,153	
Sanitary	3,500,000	130,500	75	0.336679634	1,178,379	1,305,000	2,483,379		Blackwater/Sanitary	2,195,000	82,000	75	0.336679634	739,012	820,000	1,559,012		-924,367	
Stormwater	3,500,000	87,000	75	0.336679634	1,178,379	870,000	2,048,379		Stormwater (infiltrated and treated)	1,400,500	52,000	75	0.336679634	471,520	520,000	991,520		-1,056,859	
Electricity	1,901,786		30	0.510192593	970,277	0	970,277		Electricity	1,141,572		30	0.510192593	582,422	0	582,422		-387,856	
Cable, phone, fibreoptic, etc.	998,214		30	0.510192593	509,281	0	509,281		Cable, phone, fibreoptic, etc	598,928		30	0.510192593	305,569	0	305,569		-203,713	
District heating and cooling	8,600,000		75	0.336679634	2,895,445	0	2,895,445		Hot and cold water from cogen plant	6,100,000		75	0.336679634	2,053,746	0	2,053,746		-841,699	
Building Service Connections	3,600,000	20,000	50	0.388654944	1,399,158	200,000	1,599,158		Building Service Connections	1,980,000	5,500	50	0.388654944	769,537	55,000	824,537		-774,621	
								12,675,981									**7,944,713**		-$4,731,267
Cluster Total					**59,246,134**	**30,785,000**	**90,031,134**							**62,170,473**	**10,910,000**	**73,080,473**			**-$16,950,661**
Stormwater, Wastewater, Water Supply									***Stormwater, Wastewater, Water Supply***										
Water Supply									**Water Supply**										
Present cap. Value of distribution system	2,101,500	135,000	50	0.388654944	816,758	1,350,000	2,166,758											-2,166,758	
Present cap. value of distribution system upgrade	1,190,500	76,500	50	0.388654944	462,694	765,000	1,227,694											6,271,043	
Present cap. value of treatment facilities	13,500,000	1,350,000	50	0.388654944	5,246,842	13,500,000	18,746,842		Present cap. value of treatment facilities (60% reduction)	5,400,000	540,000	50	0.388654944	2,098,737	5,400,000	7,498,737		-17,247,094	
Present cap. value of treatment facilities upgrades	2,700,000	270,000	50	0.388654944	1,049,368	2,700,000	3,749,368		Present cap. value of treatment facilities upgrades (60% reduction)	1,080,000	108,000	50	0.388654944	419,747	1,080,000	1,499,747		-3,749,368	
								25,890,662									**8,998,484**		-$16,892,178
Water Treatment									**Water Treatment**										
Wastewater (Grey- and Blackwater)																			
Present cap. value of collection system	3,501,000	130,500	75	0.336679634	1,178,715	1,305,000	2,483,715											-2,483,715	
Present cap. value of collection system upgrades	1,712,000	64,000	75	0.336679634	576,396	640,000	1,216,396											-1,216,396	
Present cap. value of treatment facilities	13,500,000	1,350,000	50	0.388654944	5,246,842	13,500,000	18,746,842		*Greywater*									-18,746,842	
Present cap. value of treatment facilities upgrades	2,700,000	270,000	50	0.388654944	1,049,368	2,700,000	3,749,368		in-building dual piping	6,110,000	60,000	75	0.336679634	2,057,113	600,000	2,657,113		-1,092,256	
									mechanical treatment (6 decentralized facilities)	4,050,000	512,000	30	0.510192593	2,066,280	5,120,000	7,186,280		7,186,280	
									add for living machine treatment (partial, 25-30%)	5,000,000	200,000	50	0.388654944	1,943,275	2,000,000	3,943,275		3,943,275	
									Blackwater										
									On-site treatment of AD leachate (6 units)	5,400,000	724,000	30	0.510192593	2,755,040	7,240,000	9,995,040		9,995,040	
									12 anaerobic digestion tanks (or one per phase)	1,500,000	650,000	30	0.510192593	765,289	6,500,000	7,265,289		7,265,289	
									Urine separation, stabilization, storage	1,200,000	250,000	30	0.510192593	612,231	2,500,000	3,112,231		3,112,231	
								26,196,321									**34,159,227**		$7,962,906
Stormwater									*Stormwater*										
Present cap. value of collection system	3,501,000	130,500	75	0.336679634	1,178,715	1,305,000	2,483,715		Present cap. value of collection system upgrades	60,000	3,000	75	0.336679634	20,201	30,000	50,201		-2,433,515	
Mega-pipe as per Wet Weather Master Plan	870,000	500	75	0.336679634	292,911	5,000	297,911		Road runoff to bioswales, infiltration basins, tanks	4,450,000	0	50	0.388654944	1,729,515	0	1,729,515		1,431,603	
Present cap. value of collection system upgrades	60,000	3,000	75	0.336679634	20,201	30,000	50,201		Green roofs, except on townhouses (12 cisterns)	400,000	0	50	0.388654944	155,462	0	155,462		105,261	
Present cap. value of treatment facility upgrades	40,000	2,000	50	0.388654944	15,546	20,000	35,546		Infiltration + treatment	395,000	32,000	50	0.388654944	153,519	320,000	473,519		437,973	
								383,658									**2,358,495**		$1,974,837
Landscaping and Paving									**Landscaping and Paving**										
Asphalt Secondary Roads	3,200,000	378,000	30	0.510192593	1,632,616	3,780,000	5,412,616		Permeable paving for secondary roads	4,404,000	378,000	30	0.510192593	2,246,888	3,780,000	6,026,888		614,272	
Basic landscaping	18,742,500	378,000	75	0.336679634	6,310,218	3,780,000	10,090,218		Deck planting, 1.5m soil, like greenroof	31,237,500		75	0.336679634	10,517,030	0	10,517,030		426,812	
								15,502,834									**16,543,918**		$1,041,084
Cluster Total					**25,077,191**	**45,380,000**	**70,457,191**							**27,540,326**	**34,570,000**	**62,110,326**			**-$8,346,866**

Appendix A: Costing Table Comparing Base Case Costs vs. Optimal Case Costs Over a Ten-Year Period

Base Case (OBC Standard)	Capital	Annual O & M	LS	Mortgage Factor x10 years	Amortized Capital Cost	10-year Oper + Main Cost	Total 10-year cost	Total by Sub-Cluster	Integrated Green Infrastructure	Capital	Annual O & M	LS	Mortgage Factor x10 years	Amortized Capital Cost	10-year Oper-Main Cost	10-year Total Annual Cost	Total by Sub-Cluster	Optimal less Base 10-year cost	Total
Energy									***Energy***										
Envelope and Construction									**Envelope and Construction**										
Apartments (3701 units)									*Apartments (3701 units)*										
Walls AG = R19	0		75	0.336679634	0		0		Walls = R30	325,688		75	0.336679634	109,653	0	109,653		109,653	
Airtightness = 0.08	0		75	0.336679634	0		0		Airtightness = 0.03 ACH incl. interior	296,080		75	0.336679634	99,684	0	99,684		99,684	
Windows = R2	0		30	0.510192593	0		0		Windows = R6	2,443,000		30	0.510192593	1,246,401	0	1,246,401		1,246,401	
Townhouses (876 units)									*Townhouses (876 units)*										
Roof = R32	0		75	0.336679634	0		0		Roof = R40	148,920		75	0.336679634	50,138	0	50,138		50,138	
Walls above ground = R19	0		75	0.336679634	0		0		Walls above ground = R30	184,836		75	0.336679634	62,231	0	62,231		62,231	
Walls below ground = R8 (2 feet below grade)	0		75	0.336679634	0		0		Walls below ground = R20 (full depth)	140,160		75	0.336679634	47,189	0	47,189		47,189	
Airtightness = 0.1 AirChange/Hour	0		75	0.336679634	0		0		Airtightness = 0.07 AirChange/Hour	87,600		75	0.336679634	29,493	0	29,493		29,493	
Windows = R2	0		30	0.510192593	0		0		Windows = R6	925,000		30	0.510192593	471,928	0	471,928		471,928	
								Base									**2,116,716**		$2,116,716
HVAC									**HVAC**										
Apartments (3701 units)									*Apartments (3701 units)*										
Partially conditioned supply to corridor (25 L/s per unit) w indiv'l bath exhaust fan(s)	4,811,300		25	0.559382903	2,691,359		2,691,359		Central ventilation with dehumidification capability	0		25	0.559382903	0	0	0		-2,691,359	
No Ventilation Energy Recovery	0		25	0.559382903	0		0		Ventilation Energy Recovery 75% (85% w/preheat)	8,512,300		25	0.559382903	4,761,635	0	4,761,635		4,761,635	
No Ventilation Energy Recovery	0		25	0.559382903	0		0		Central Ventilation Preheat	185,050		25	0.559382903	103,514	0	103,514		103,514	
Space heating by Incremental heat pump backed up by mid-efficiency boiler	12,953,500		25	0.559382903	7,245,966		7,245,966		Space heating by Central supply with building HX	0		25	0.559382903	0	0	0		-7,245,966	
Service water heating mid efficiency gas boiler	1,850,500		25	0.559382903	1,035,138		1,035,138		Service water heating hx from central supply storage at building	925,250		50	0.388654944	359,603	0	359,603		-675,535	
No greywater heat recovery	0		25	0.559382903	0		0		Greywater heat recovery	1,110,300		50	0.388654944	431,524	0	431,524		431,524	
Building H/C Distribution Short ductwork from heat pump fan	4,441,200		25	0.559382903	2,484,331		2,484,331		Building H/C Dist. Radiant heating + cooling coupled w dehumidified vent'n supply air	9,252,500		75	0.336679634	3,115,128	0	3,115,128		630,797	
Townhouses (876 units)									*Townhouses (876 units)*										
Ventilation: Principal exhaust fan with supplementary bath exhaust fan	1,314,000		25	0.559382903	735,029		735,029											-735,029	
No Ventilation Energy Recovery	0		25	0.559382903	0		0		Ventilation Energy Recovery 75% (85% w/preheat)	1,752,000		25	0.559382903	980,039	0	980,039		980,039	
Space heating by mid-efficiency gas forced-air furnace	3,285,000		25	0.559382903	1,837,573		1,837,573		Space heating by Direct central supply	0		25	0.559382903	0	0	0		-1,837,573	
Space cooling by 2 ton split system w/DX coil in forced air supply	2,847,000		25	0.559382903	1,592,563		1,592,563		Space heating by Direct central supply	0		25	0.559382903	0	0	0		-1,592,563	
Service water heating by mid efficiency gas hot water heater	1,314,000		25	0.559382903	735,029		735,029		Service water heating hx from central supply	876,000		25	0.559382903	490,019	0	490,019		-245,010	
No Greywater Heat Exchange	0		25	0.559382903	0		0		Greywater Heat Exchange	438,000		25	0.559382903	245,010	0	245,010		245,010	
Building H/C Distribution: Forced air ductwork with furnace fan	1,752,000		25	0.559382903	980,039		980,039		Building H/C Dist. Radiant heating and cooling coupled with dehumidified vent'n	2,628,000		25	0.559382903	1,470,058	0	1,470,058		490,019	
								19,337,028									**11,956,530**		-$7,380,498
Electric									**Electric**										
Apartments (3701 units)									*Apartments (3701 units)*										
Lights: Standard efficiency fixtures and bulbs	0		20	0.648717765	0		0		Lights: Improved efficiency fixtures and bulbs	185,050		20	0.648717765	120,045	0	120,045		120,045	
Appliances: Standard efficiency appliances	0		20	0.648717765	0		0		Appliances: High efficiency appliances	555,150		20	0.648717765	360,136	0	360,136		360,136	
Standard Furnace Fan	0		20	0.648717765	0		0		Single Circulation Pump	185,050		20	0.648717765	120,045	0	120,045		120,045	
					0		0												
Townhouses (876 units)					0		0		*Townhouses (876 units)*										
Lights: Standard efficiency fixtures and bulbs	0		20	0.648717765	0		0		Lights: Improved efficiency fixtures and bulbs	43,800		20	0.648717765	28,414	0	28,414		28,414	
Appliances: Standard efficiency appliances	0		20	0.648717765	0		0		Appliances: High efficiency appliances	219,000		20	0.648717765	142,069	0	142,069		142,069	
Standard Furnace Fan	0		20	0.648717765	0		0		Single Circulation Pump	43,800		20	0.648717765	28,414	0	28,414		28,414	
								Base									**799,123**		$799,123
							0												
Heating and Cooling Supply (Building Level)							0		**Heating and Cooling Supply (District)**										
Common Building Equipment	4,700,000		25	0.559382903	2,629,100		2,629,100		Central Equipment (2 MW) -$2,000,000 credit	23,042,500		25	0.559382903	12,889,581	0	12,889,581		10,260,481	
									Plant building	3,750,000		75	0.336679634	1,262,549	0	1,262,549		1,262,549	
									Site Distribution	4,200,000		75	0.336679634	1,414,054	0	1,414,054		1,414,054	
								2,629,100									**15,566,184**		$12,937,084
Operation and Maintenance		1,373,000				13,730,000	13,730,000		**Operation and Maintenance**		1,250,000			0	12,500,000	12,500,000		-1,230,000	
Site Energy		9,080,700				90,807,000	90,807,000		**Site Energy**		4,254,240			0	42,542,400	42,542,400		-48,264,600	
								104,537,000									**55,042,400**		-$49,494,600
Cluster Total					**21,966,128**	**104,537,000**	**126,503,128**							**30,438,553**	**55,042,400**	**85,480,953**			**-$41,022,175**
																		OVERALL	**-$66,319,701**

APPENDIX B: ANALYTICAL FRAMEWORK

	FOOD	WATER SUPPLY	WASTEWATER	STORMWATER	ENERGY	TRANSPORTATION	MSW	BELOW GRADE SERVICE LEVEL
BELOW GRADE SERVICE LEVEL	- Location for related materials equipment and supplies.	- Location of storage cisterns and auxiliary equipment; pumps, filters etc. (5) - Potential for potable water storage, or suitable fire protection water storage, to meet peak demands.	- Accessible route location. (5).	- Accessible route location. (5) - Location of storage cisterns and auxiliary equipment. - Integrate stormwater transfer within structure to enhance and distribute ground water return.	- Accessible route location. (5) - Plant location - Thermal storage location - Reduce surface impermeability by relocating parking etc. allowing improved surface solar control treatments eg. trees	- Weather protected public circulation - Parking, car share co-ops, leasing - Service and delivery routes with loading/ unloading locations - Facility would encourage reduction of local transportation.	- Location of storage - Access for collection by truck or vacuum system.	- Relocate parking, delivery and vehicle obstruction from grade positions allowing greening of grade and improved through traffic circulation - Improved services access and distribution - Net capital and operating cost savings - Future servicing flexibility.
MUNICIPAL SOLID WASTE (MSW)	- Collection of organic waste (household or food-industrial) for composting - Compost returned to agriculture (urban or rural) (3) - Potential local composting - Nutrient recovery from anaerobic digestion.		- Combination of wastewater and MSW for anaerobic digestion to produce energy (2).		- Anaerobic digestion to produce energy - Landfill greenhouse gas (GHG) recovery - Incineration with heat recovery.	- Vacuum chute conveyance to reduce amount of vehicular transportation of waste (2).	- Reduce landfill - Potential renewable energy supply - Probable net cost equivalency, except for the vacuum system which must also consider societal benefits.	
TRANSPORTATION	- Avoidance of some transportation of food by localizing agriculture.	- Water supply shares ROW with transportation (both roadways and parking) (1).	- Conveyance could share ROW with transportation (1) - Wastewater to be used to produce biogas for transportation (2).	- Water quality affected by road runoff and de-icing salts - Bio-infiltrated stormwater can be conveyed via subsurface flow along ROW (1).	- Buses using biogas from household organic and/or municipal waste (2) - Streetcars/trolleys running on electricity generated from renewable source (wind, solar, biogas) - Electric can car recharging stations - Solar collectors and/or wind turbines sharing ROW with transportation (1).	- Reduce reliance upon non-renewable energy sources.		
ENERGY	- Rooftop gardens equivalent energy performance to green roofs.	- Spent water from geothermal district heating/cooling water re-used for non-potable uses; or routed to treatment plant for treatment to potable water (1).	- Wastewater biogas generation (1) (2) - Heat-pumping energy from sewage - Site energy production facility with wastewater treatment plant; a reliable, embedded source of power in case of emergency, such as blackout e.g. solar device can enclose wastewater treatment facilities.	- Facilitate water recovery for transport and treatment energy savings.	- Renewable energy and nutrients reduce demands for conventional energy. - Local operation can back up and reduce demands of local electrical infrastructure. - Offline generation, geothermal and active storage and demand management strategies.			
STORMWATER	- Rooftop stormwater retained for rooftop urban agriculture (3).	- Capture, retention, treatment and reuse of stormwater - Non-potable water re-used for irrigation, toilet flushing, and other non-potable uses (4).	- Conveyance has historically been inappropriately connected - In new developments, stormwater may be captured after bio-infiltration in underground cisterns, then pumped via greywater pipes to greywater treatment (1) (4) - To deal with current Combined Sewer Outfall issues, outfalls may be released into a retention pond for catchment rather than into lake - CSO can also be released to a sequenced wetland.	- Recovery / storage reduces impact upon municipal infrastructure. Local treatment reduces flow handling and receptor pollution - Unloads mains and treatment facilities - Infiltration is very cost effective - Reuse has long payback at current subsidized rates.				
WASTEWATER	- Sludge from wastewater, following AD, can be treated to remove metals and biotoxins, then applied to agricultural fields.	- Water cascading; reuse of water for non-potable uses wherever possible (4) - Wastewater treatment for non-potable reuse to conserve potable water usage.	- Reduce landfill - Potential renewable energy supply - Probable net cost equivalency - Unloads mains and treatment facilities.					
WATER SUPPLY	- Water supply for food production sourced via stormwater retention in areas where aquifers are endangered.	- Storage can reduce load impact upon surrounding supply infrastructure - Unloads mains and treatment facilities.						
FOOD	- A potential local industry, or at least self supply. (3)							

Examples of multiple integrations of primary infrastructure:

(1) Transportation Right-of-Ways used to house buried infrastructure such as water supply, wastewater, electricity, DLWC water, biogas, communications, etc; thermal solar collectors, photovoltaics, and wind turbines for localized renewable energy production; and green stormwater management infrastructure, such as trees and bioswales.

(2) Wastewater combined with household organics (may be facilitated by vacuum chute conveyance) to produce biogas, which can in turn be used directly in homes for cooking and heating, or be used in cogeneration to produce heat and electricity, or can be used as alternate fuel by vehicles.

(3) Industrial ecosystem employed such that organic waste from households (i.e. foodscraps) or industry (e.g. brewery, bakery, etc.) is composted and used to grow produce. System is fed by non-potable water and can be used as a greywater treatment facility.

(4) "Water-cascading" where potable/non-potable water supply, stormwater, wastewater, and spent geothermal water are integrated and reused in localized recycling of water. For example, spent geothermal water undergoes treatment to potable standards, is used for bathing, then treated to be used for toilet-flushing; resulting blackwater undergoes treatment to non-potable standards and is used for irrigation.

(5) Installation in below grade space saves capital and service costs.

*** This table is intended to facilitate the identification of preliminary relationships between two primary infrastructure components. Multiple integration examples are denoted by numbers in brackets throughout the table and described above. Neither the relationships in this table nor the examples described are exhaustive.**

Colour Key:

- Effective synergy: economically, environmentally, and socially sustainable
- Good synergy:; not certain if all three levels of sustainability met
- Relatively minor or indirect synergy; advised if convenient
- Mutually beneficial relationship