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District Heating Techniques for Reduction of Carbon Footprint

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Abstract—*A carbon footprint is "the amount of carbon dioxide or other carbon compounds emitted into the atmosphere by the activities of an individual, company or country". Typically a carbon footprint is measured over a specific amount of time such as one year. There are so many things that we all do on a daily basis that have an effect on our environment. i.e. The energy we use in our homes. How many lights and electronic devices we have plugged in and running at once, our home thermostat and our laundry habits create our carbon footprints.*

District heating system can provide cost-effective and low-carbon energy to local populations, such as space heating in winter and year-round hot/cold water; this is also associated with electricity generation in combined-heat-and-power systems. In India including the Renewable Heat Incentive, aim to increase the amount of energy from such sources; including new installations, as well as extending/upgrading existing distributed energy schemes. Country should have award-winning district energy network, incorporating city-wide heat distribution. This paper aimed to demonstrate the opportunities for expansions to this through geographical information systems of the heat demands in the city. 'Heat maps' can beproduced; locating existing and emerging heat sources and sinks. A number of current and emerging heat sources are also discovered – potential suppliers of thermal energy to the above-defined heat sinks. From these 'heatzones' an expansion to the existing network could be possible to identified and the infrastructure planned for each development.

1. INTRODUCTION

District heating system(DHS) offers excellent opportunities for achieving the twin goals of saving energy and reducing carbon footprint. It is an extremely flexible technology which can make use of any fuel including the utilization of waste energy, renewables and, most significantly, the application of combined heat and power (CHP). It is by means of these integrated solutions that very substantial progress towards environmental targets, such as those emerging from the Kyoto commitment, can be made.

While designing and implementing the conversion of buildings to chilled water based district cooling systems, for example, the distribution of chilled water at a temperature between 1°C and 4°C and a maximum pressure of 1.0 MPa (150 psig). These data will be applicable to a variety of building types, including residential, commercial, institutional and industrial.

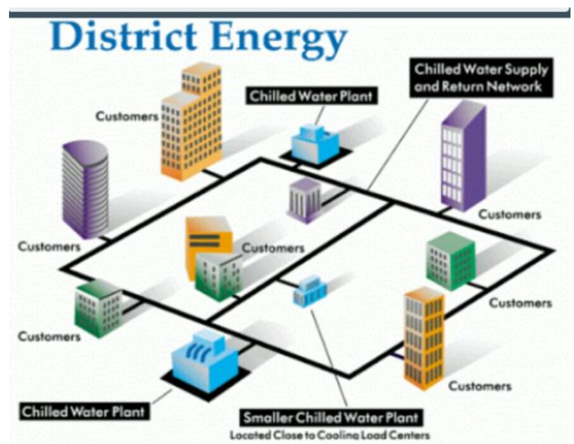

Fig. 1: District heat energy Distribution

The conversion procedures is concentrate on the types of conditions most likely to be found in cold weather countries i.e. centralized chilled water district cooling systems, service to a variety of building sizes and types, applicable to both new and existingprimarily on larger buildings. It's always possible the indirect and direct connection between the district chilled water and building systems.

To provide practical advice on converting buildings in the most cost-effective manner while ensuring that the system is technically sound and provides reliable and efficient cooling using a district cooling system. Design and installation.

In all times, the engineer should always consult the district cooling utility. The design engineer shall be responsible for the detailed design, specification, and final selection of all equipment, systems, and components.

Form water retention technologies. Byusing DHS rather than a traditional rooftop mechanical room, space is made for water retention technologies that could not otherwise be built. By reducing the amount of water flowing from a building site, municipalities reduce the risk of sewer overflows and can reduce the infrastructure required for storm water containment. Lastly, a DHS produces thermal energy on a large scale and is technology neutral. The nature of DHS allows for fuel diversity and flexibility. Should the cost of any one type of fuel increase dramatically in price, DHS have the ability to switch sources with minimal investment.DHS will allow municipalities to ensure their communities will be able to maintain reasonable fuel costs and a high standard of living. None of these economic benefits are included in current feasibility analyses yet they can be substantial. If these factors were included, the economic case for DHS would be made quite easily and communities could then benefit from the reduced carbon footprint for their heating and cooling.

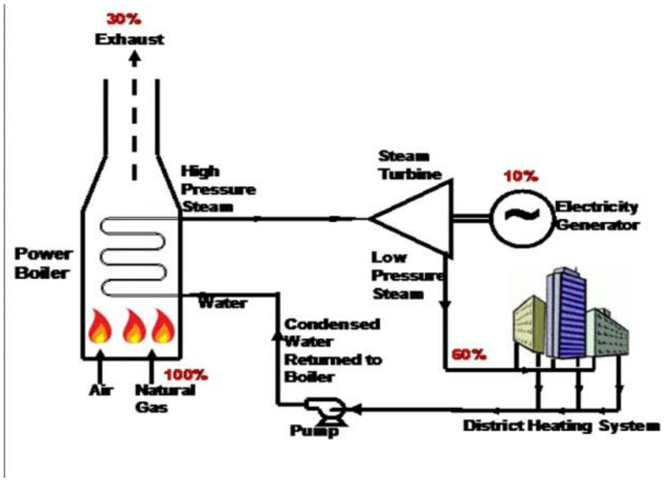

Fig. 2: Schematic diagram of DHS

2. ENERGY SECURITY AND REDUCING INFRASTRUCTURE COSTS IN POWER GENERATION AND WATER MANAGEMENT

A District heating system (DHS) has the potential to help governments, at all levels, reduce operating and infrastructure costs. These opportunities, however, are often left unexplored. In a free market environment, DHSdevelopment will only take place with a strong business case for a DHS Utility and its customer base. By recognizing and crediting the cost savings that a DHS affords governments, the business case for DHS would be strengthened and help policy makers to take advantage of the eco-efficiencies these systems provide.

Governments are averse to providing financial or human capital to support the private sector without a reasonable expectation of socio-economic benefits for taxpayers. While these capital intensive systems do not necessarily need government support to be economically viable, returns are often marginally below acceptable levels for investors. By helping the private sector breach the risk/reward threshold, municipalities could reduce their own operating costs by millions of dollars with minimal investment and risk.

To realize the additional benefits of DHS, it is crucial to understand what district energy systems are, the current business case for district energy, and the economic and environmental opportunities that are complementary to government objectives such as: power generation, storm water management, energy security, and economic growth.

District energy is a technical solution for providing the thermal energy used for conditioning indoor spaces. DHS are generally comprised of three major components:

- A common or shared energy generating facility referred to as a central energy plant or community energy centre,
- A system of interconnected pipes that link the energy centre(s) to multiple buildings referred to as a distribution piping system or thermal grid,

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- A thermal interface at the customer building referred to as a customer substation or energy transfer station.

In the case of district heating system, hot water (or steam) is transported through a sys- tem of pipes and delivered to the customer buildings for space heating and domestic water heating. The heat energy carried in the fluid is extracted by the building's systems and the cooled water is returned to the central energy centre, in a closed loop piping system, where it is reheated for redistribution. Similarly with district cooling, chilled water is pumped through a network of pipes and the cooling energy is extracted by the building for air conditioning or process cooling and then the warmed water is returned to the plant to be cooled again.

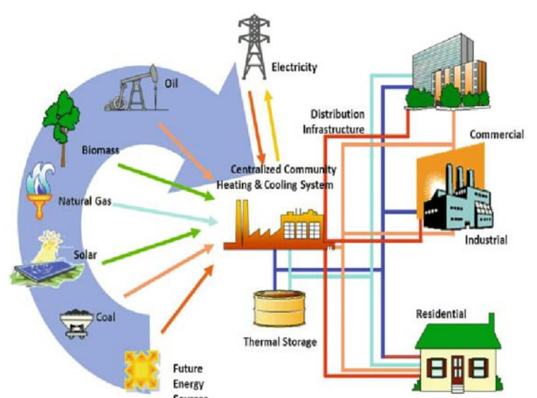

Fig. 3: illustrates that DHS is not technology specific

Multiple or single fuel sources and/or technologies can be employed including but not limited to: absorption chillers, ambient cooling, deep lake water cooling, combined heat and power, biomass incineration, waste incineration, geothermal, and conventional boiler and chiller technologies.

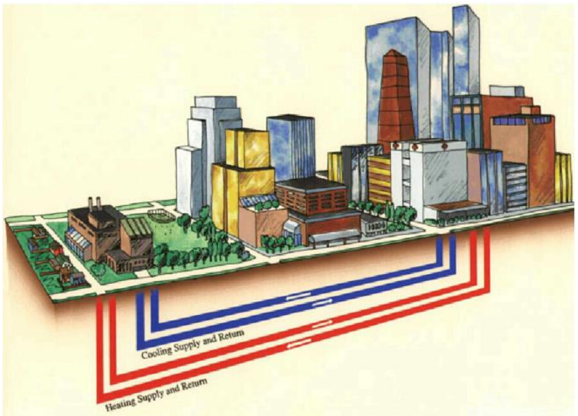

Fig. 4: illustrates how DHS typically works.

Pipes run underground bringing heating and cooling energy to buildings from a central energy plant.

Economies of scale and advancements in technology have enabled DHS to achieve greater efficiencies than individual building systems. Serving multiple buildings from a common facility allows for large scale systems to be built that can accommodate state-of-the-art technologies in heating and cooling. For example, individual buildings could not cost effectively make use of natural lake water cooling or Combined Heat and Power (CHP). Using natural sources of cooling or waste heat sources from manufacturing or electricity generation can reduce energy consumption for the production of thermal energy to near zeroIn addition, economies of scale in DHS enable the efficient use of convention- al equipment by:

- Having purpose built facilities that are actively maintained and operated
- Aggregating thermal loads from multiple and a variety of pes of buildings so that equipment can be run optimally with less part loading.

Thermal energy generating equipment such as boilers and chillers operate most efficiently at a single load factor (Chan 2002). This concept is analogous to the fuel efficiency of a car, reaching optimal fuel economy between 50 and 80 km/h (NRCAN 2012a, b). A car traveling outside of its 'sweet spot' will use more fuel per km travelled. Likewise, a boiler or chiller will use more energy for every unit of thermal heating or cooling when forced to operate above or below its 'sweet spot'. By having an aggregated load, a DHS can 'stage' its boilers and chillers by operating only the number required by while maintaining each in its efficiency 'sweet spot'.

The earliest DHS is dated as far back as the 1300s The first known system distributed warm water through a series of wooden pipes in France. In 1877, the first commercial DHS was built in New York (CDEA 2011DHSare not a new concept. Though widely embraced in Europe, DHShave not seen the How District Energy Systems can be used to Reduce Infrastructure Costs 199 same rate of adoption in North America. Abundant and low cost energy supplies have reduced the urgency for conservation and innovation in thermal energy production. However, energy constraints, limited dollars, and environmental concerns are putting DHS on the public agenda. To address these concerns, policy makers can examine the synergistic opportunities that DHS can provide.

3. A CASE FOR DHS

A case for DHS fails to examine or value the economic and environmental benefit to other stakeholders such as industries, communities, and governments. The industry standard for determining the feasibility of investing in DHSis based solely on the economic benefit to both the building owner(s) (customers) and the DHS utility.

For the DHS Utility, the profitability of developing a DHS is evaluated by com- paring the initial capital investment costs to the expected cash flow over the life of the system. Capital costs include the cost to build the DHS infrastructure: the energy centre, the distribution piping system, and the customer connections. Expenses are dictated by fuel, operating, maintenance, and administration costs. Revenue is based on a capacity charge to the customer as well as energy delivery charges. The price is dictated by the Business-As-Usual (BAU) cost to produce thermal energy for space heating, cooling, and domestic hot water. After a financial analysis, the DHS Utility decides if the business case for DHS passes the risk/reward threshold that the investor is willing to accept.

A similar economic analysis is performed by the building developer or owner comparing the price of the district energy service to the current (or estimated) capital and operating costs of providing building heating and cooling. The district energy service is priced competitively, equal to or below, the BAU model. The cost savings a building would realize by connecting to a DHS is comprised of some or all of the following:

- Reduction in initial and/or replacement capital cost for major mechanical equipment including cost of associated space, electrical installation, and auxiliaries
- Fuel costs (i.e. natural gas for heating, and electricity for cooling)
- Cost of water, sewer, and water treatment
- Equipment operating and maintenance cost, including yearly preventative maintenance and ongoing repair/over haul costs
- Cost of labor, administration, and insurance
- Value of ''freed up'' roof space, greenhouse gas reduction, risk mitigation, and liability.

Three to opportunities are their respect to DHS benefits can be found in:

- Reduction in electrical generating capacity,
- Storm water management, and
- Improving energy security: risk mitigation and management.

The important benefits listed above, may not be categorized as direct benefits to either the DHS Utility or the building owner, however, they are the only two parties paying for DHS development. Measuring and giving credit to the private sector for the positive contributions of DHSto the public sector, would help policy makers take advantage of synergistic eco-efficiencies.

4. REDUCTION IN ELECTRICITY GENERATION

4.1 Eco-efficiency Opportunity

In most countries, the electrical grid faces the most strain during the hottest days of the year due to the electricity requirements for air conditioning. Cooling loads, however, can vary substantially throughout the day and because the highest electricity demand comes in the summer time during the hottest time (IESO 2010), the greatest benefit from conservation efforts will come from reducing energy demand at that time.

1 kWh saved during peak time is more significant than one saved at night. Exacerbating the problem, line losses are higher during peak times than low usage times. When the electricity transmission and distribution systems get hotter, the loss can be substantially higher than the average. In Ontario, the variation ranges from 5 % during low usage times to 25 % during peak hours according to an Ontario Hydro study. Taking into account the total losses from generation to delivery, saving 1 kW during peak times can reduce generating requirements by 1.47 kW (Ontario Hydro 2007).

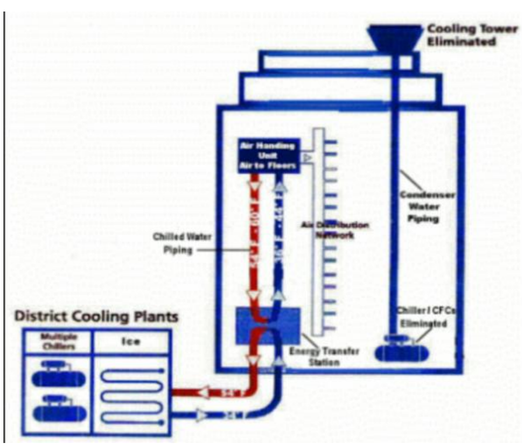

Fig. 5: Shows particular buildingswitched from running its own chillers to a DHS

By reducing peak demand, the province can reduce its use of the less environmentally attractive resources that are called on when demand is high. In the long run, lower peak demand will mean less need for new generating facilities and transmission and distribution infrastructure

The electricity demand of a 30 story office tower for the year before the transition to district cooling and after. It is indicative of the savings that DHS could provide. The

Electrical load before and after conversion to DHS for a glass building demand in electricity drops by roughly one third at the time of switchover. Reducing electrical demand translates into fewer gas fired generating stations needing to be built in populated areas.

2 Savings CostBenefits

Electrically driven chillers for the most part generate more than 1 thermal unit of cooling energy for each unit of electricity. Rather than reference efficiencies in terms of percentages greater than 100, it is common practice to refer to chiller efficiencies in terms of Coefficient of Performance (COP). A fairly inefficient chiller with a COP of 3 produces 3 units of thermal energy for each unit of electrical energy. Assuming that chillers in the DHS on average can produce a COP of 5 (requiring 0.1 kWe of electricity per kWth) compared to a BAU COP of 3 (requiring 0.3 kWe of electricity per kWth) (mostly due to scale efficiencies) at peak times, each kilowatt thermal (kWth) of cooling demand translates to 0.2 kWe of electricity demand reduction.

If DHS utilities are able to capitalize on their size and generate and store chilled water at night (instead of producing it during the day), the peak time generation demand can reduce the cooling energy to effectively zero, saving 0.5 (kilowatt electrical) kWe for each kWth of cooling required. In the case of free cooling by snow, lake water, or other natural sources, the peak time savings are also on the order of 0.5 kWe for each kWth of cooling since in both cases of chill storage and free cooling, only pumping energy for the water is required.

Table 1 gives the possible load reductions.

For a contracted gas fired power plant.

Table 1: Peak reductions cooling (at source)/kWthat generation source per kWth cooling due to DHS when compared to BAU

Table 1Peak reduction by District heating System	
Centrifugal chillers	0.1–0.3 kWe
Thermal storage	*0.5 kWe
Free Cooling	*0.5 kWe

Every MW of generation that can be avoided translates into significant savings.

4.3 Environmental Benefits

Reducing electricity use at peak times not only reduces the need to build more generating capacity, it potentially reduces carbon footprint and Greenhouse Gas (GHG) emissions.

Ontario, for example, uses a combination of nuclear and hydro power to satisfy the base load of electricity. As demand increases, the source of power tends to get dirtier.

As demand increases, carbon footprintsand GHG emitting sources of generation come online. By using less energy during peak times (usually from noon to early evening), DHS can reduce CO2e,NOx, and SOx in the atmosphere

It is readily apparent that a base load is supplied by nuclear and hydro while natural gas

How District Energy Systems can be used to Reduce Infrastructure Costs

Table 2: NOx and Sox output for various electricity generation forms (NRCAN GHGenius 2010) g/kWh

	Coal	NG Boiler	NG Turbine	Nuclear	Hydro
NOx	2.64	0.59	0.56	0.00	0.00
SOx	4.96	0.01	0.01	0.00	0.00

Is the first choice for marginal requirements. As the demand increases, coal starts to come online as a last resort given how dirty it is.

Table 2 shows the difference in NOx and SOx output between different forms of electrical generation. Ontario still requires coal to meet its demand at peak times. Coal fired power plants produce nearly 3 g of NOx for each kWh of electricity and 5gSOx for each kWh of electricity. Conversely, nuclear and hydro do not add carbon footprint (during the operational phase of the life cycle). Using DHS to simply shift what time electricity is used for heating and cooling buildings could have a dramatic effect on pollutant emissions.

Although, studies have shown the correlation between NOx, and SOx with asthma and other respiratory illnesses (Lebowitz 1996; Detels et al. 1991), the cost savings from reducing emissions is difficult to calculate. Countries such as Canada, with government funded health care, can consider the cost savings associated with reducing the incidences of asthma and related respiratory illnesses as a bottom line benefit. A person with asthma in Ontario will on average cost the health care system twice what a person without the disease would cost (To 2007). If regulators and medical professionals can estimate the correlation between health care costs and the amount of carbon footprint in the air, policy makers can begin to understand the dollar value of preventative versus reactionary health care costs.

In the same way that atmospheric carbon footprint can be reduced, DHScan play a role helping countries meet GHG reduction targets. The authors conducted a study based on the electrical output in Ontario for 2009 and 2010;

Table 3 shows that DHS could decrease GHG emissions by as much as 145 g of CO2e for each kWh of thermal cooling.

In many jurisdictions, there is no value assigned to GHG reduction. In these areas, DHS utilities and building owners receive no economic benefit for the reduction in GHGs that a DHS offers. Governments can encourage adoption of DHS by providing an incentive equal in value to reduction initiatives. Alterna- tively, a fee or tax on emissions could incentivize connection to DHS.

Table 3: Cooling (IESO, NRCAN 2010)

	Centrifugal chillers	Thermal storage	Free cooling
GHG reduction per KWhth	67g	35-145g	145g

Putting a price tag on GHG emissions and carbon footprint reduction may not be popular in many jurisdictions but policy makers should recognize its merits. Deciding the value of each ton of GHGs reduced and applying that value to projects could spur innovation beyond DHS.

5. ENERGY SECURITY:

Risk Mitigation and Management

5.1 Eco-efficiency Opportunity

DHS provide governments an opportunity to protect the reliability of local energy systems through conservation, diversity, flexibility, and availability. The International Energy Agency (IEA) defines energy security as ‘‘the uninterrupted physical availabilityat apricewhichisaffordable, whilerespecting environmental concerns.’’ Withthegrowth ofurbancentersandtheassociatedenergy intensification requiredto provideessential services, governmentsareincreasinglychallengedtoaddress issues of energy security. DHScan address factors, such as supply, price stability, and sustainability that contribute to greater energy security and independence.

The DHSthermal grid which connects energy producers to end-users aids in conservation efforts. This connection allows waste heat from industrial or power generating processes to be used for residential and commercial heating. By uti- lizing waste heat sources, DHS reduce the amount of fuel burned for space heating and improve the efficient use of fossil fuels.

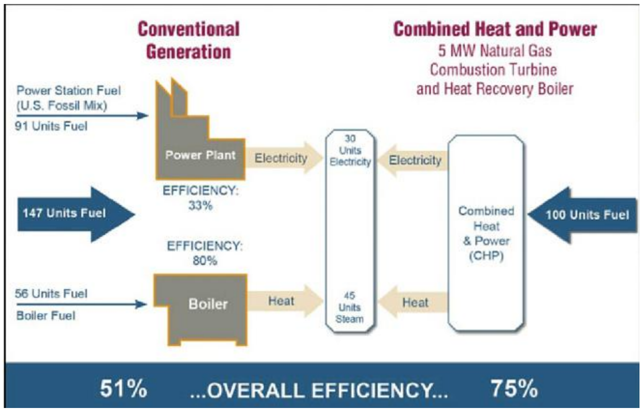

Fig. 6: illustrates that using waste heat from conventional power production, a concept known as CHP, can increase system efficiency and reduce fuel input from 147 to 100 units, a 30 % reduction. It is estimated that 61 % (OEE 2008) of building energy usage in Canada is used for space heating and cooling and water heating; a 30 % reduction fuel used in buildings is substantial. Waste and renewable fuels are available for heating and since fossil fuels are finite, there is value to reserving this precious resource for applications that have no other alternative such as pharmaceuticals and medical devices and equipment.

DHS can expand the diversity of fuel types used for heating and cooling by taking advantage of local fuel sources that would otherwise remain unused. Fuels such as biomass (wood chips, sawdust, straw), geothermal, biogas, and municipal waste are difficult to manage on a small scale—largely due to handling issues. The availability of local fuel sources and the ability to use them reduces the reliance on supplies from countries or jurisdictions that may be adversely affected by war, politics, or natural disaster. According to SandorBoyson, research professor and co-director of the Supply Chain Management Center, ‘‘the longer the supply chain, the more that can go wrong and the more it costs with high gas prices.’’

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(University of Maryland, date unknown). In other words, a diverse fuel mix that incorporates local sources increases energy independence and reduces risk of sup- ply interruptions and price instability.

The thermal grid and the centralized nature of energy production facilities allow DHSto support fuel switching and the implementation of state-of-the-art technologies. These qualities are referred to as fuel flexibility and technology flexibility; both improve the ability to optimize energy production in terms of cost and efficiency. The scale and centralized nature of DHSallow multiple fuel sources and/or technologies to be integrated at one location at a lower cost, than at many, in each individual building. In some cases certain fuels and technologies cannot even be applied on an individual building scale.

5.2 Cost Savings

The risk of not addressing energy security is real and can have a significant impact on the economy. Costs can be examined from at least two perspectives:

- Cost of interrupted to fuel/energy supply
- Cost of the inflexible nature energy production.

The recent power outage in India of July 2012, the North-eastern Blackout of August 2003, and the North American Ice Storm of January 1998 are only a few reminders of our reliance on energy. An estimate of the economic impact of the North-eastern Blackout of 2003 is in the range of $7.0 billion dollars (USD) from food spoilage, lost production, wages, etc. with the loss of 61,200 MW (ECLON

2004). Using the above figures, the economicimpactofanenergy supply interruption could be on the order of magnitude of $114,000 (USD)/MW of electrical supply loss (over the outage period). A catastrophic failure, similar in duration, of the W.A.C. Bennett Dam in B.C. at 2,730 MW or the Adam Beck I and II (Niagara River) in Ontario at 2,278 MW can have an economic impact in the order of $228 M (USD).

The value of mitigating energy (thermal and electrical) supply interruptions and pricing is difficult to estimate. As a gross estimate, municipalities could estimate the value of lost productivity as a function of the average GDP. This may help put into perspective the cost of each hour of unavailable electricity and thermal energy.

The inability of buildings to retrofit existing equipment to use alternate or renewable fuels or to implement more efficient technologies can reduce the competitiveness and robustness of an economy. Many industries, businesses (especially small ones), and households would encounter financial difficulties dealing with the consequences of a sharp increase in energy prices. Fluctuating energy prices can have a negative effect on many industries such as manufacturing, mining, transportation, forestry, and agriculture resulting in unemployment, loss of skilled labour and high paying jobs, as well as higher priced food and consumer goods resulting in a decreased standard of living

The value of being prepared for changes in the future, of being flexible, and of having a diversity of local fuel sources can be estimated by exploring the capital cost to modernize existing building heating and cooling systems for a group of buildings compared to a large scale DHS. Additional factors to examine can include depreciated building value and the exposure to utility cost fluctuations of relying on a single fuel source for example, electric baseboard heating).

5.3 Environmental Benefits

Retrofitting hundreds of small boilers to use waste wood, bio-fuels, or solar energy would be much more expensive than modifying a single energy centre. The ability to switch fuels in a cost-effective manner means a higher likelihood of space heating and cooling needs being met by renewable sources.

Oujé-Bougoumou, an early adopter of DHS in Canada has found that the presence of DHS has displaced conventional energy sources such as fossil fuel and raised community awareness to environmental issues (Ouje 2012).

Energy is integral to modern living and the impact of energy supply interruptions is real and tangible. Through conservation, diversity, and flexibility, DHS contribute to greater energy security and independence.

6. BENEfiTS BEYOND PRICE

In evaluating eco-efficiency opportunities, in some cases, there are direct costs; Not all benefits have obvious or cost savings. For example reducing the incidence rate of asthma and other pollutant related diseases could reduce the burden on state funded health care systems but it is difficult to put a price tag on the value of a healthy person or improved quality of life. Important questions to ask when developing sustainability plans include:

- What is it worth to the city/town to avoid living next to an electricity generator?
- What is it worth of reducing air emissions? If a price cannot be put on health, can a price be put on net emissions?
- How much has it cost to the economy, historically, when the electricity grid fails? How much financial risk is the municipality willing to accept?

There are challenges to limiting evaluation metrics to only measurable cost but it does not diminish the value of considering externalities such as clean air and water, improved health, community engagement, and public opinion.

By reaching outside of the direct cost benefits and including ancillary benefits to the analysis, the authors hope to create a broader more accurate evaluation of DHS and the role it plays in reducing demands on energy infrastructure and consumption.

7. RECOMMENDATIONS

Municipal, regional, and federal governments should take advantage of the real dollar savings that DHS affords. This can only be done by identifying, under- standing, and quantifying the costs and eco-efficiencies that DHS could save municipalities.

Table 4 opportunities and benefits

Table 4: Eco-efficiency opportunities of DHS systems

Eco-opportunity	Benefit	Metric/Key performance indicators
Electricity generation	Demand reduction	kW demandreduction/kW generating capacity reductionAir pollution reduction
Storm water reduction	Runoff reduction	%/$ reductionin mitigation
		Water pollution reduction
Economic risk mitigation	Electrical grid stability	% reduction of blackouts
	Energy price stability	Reduce volatility
	Fuel flexibility	Minimize time to convert primary fuel sources

carbon footprint reduction management %/$ Electrical grid Energy price stability identified. The metrics and key performance indicators can be used as a guide for developing sound public policy surrounding DHS. Without strong public policy to lead the way, the full environmental benefits of DHS will be difficult to realize.

Beyond financial incentives or economics, the greatest hurdle to developing DHS, as in any business, is getting customers—without customer buildings, there can be no DHS development. Even with a business case, signing customers is challenging because the status quo or engrained industry practices are difficult to overcome. People are generally adverse to change current business practices, especially when a proven method is achieving good results. Exacerbating the problem, many buildings are built and developed by a separate entity which owns and operates the building leaving little incentive to seek out efficiencies, reduce GHG emissions, or address energy security. All levels of government can do more to encourage DHS development and bridge the gap toward affecting change.

- •Public buildings should lead the way and be the first to connect to DHS
- Main mechanical room located in the basement or ground floor level,
- A centralized water-based (hydronic) heating and cooling system,
- Lowest hot water return temperatures and highest chilled water return temperatures as possible,
- High density or energy usage buildings, situated in close proximity to one another with a variety of usages.

There is often strong resistance to being the first to use a new or different technology or system. By leading the pack, government buildings can reduce the apprehension of other building owners by providing an example to inspire.

- Create a Customer Base

The authors also recommend that municipalities or regional governments establish minimum performance requirements in their jurisdictions.

8. FURTHER RESEARCH

To help municipalities and regional governments policy makers must quantify their costs in managing storm water, securing electrical capacity, and addressing energy security in order to realize the potential synergies and cost savings. managersShould design appropriate incentives to reduce overall costs to the municipality.

Electrical utilities are common and the cost of each additional kW of new generation (for each technology) is fairly well studied, however, societal costs are of-ten ignored and focus only on design and construction costs. The cost of over-coming public outrage to this type of infrastructure should be taken into account when determining an overall cost per kW of additional generation. This will help policy makers appreciate the cost of cancelled plants, relocations, and other risks that are often difficult to budget.

9. CONCLUSION

It is critical to recognize the benefits of energy reduction techniques and the multiple benefits of DHS to identify eco-efficiency opportunities. municipalities and regional governments can make sustainable initiatives more cost effective for all parties—and in doing so reduce infrastructure costs and Environmental impact.

Recognizing how systems interact with each other and the benefits they provide is an essential part of developing sustainable systems. The recognition of cost reduction and environmental benefits will allow governments at multiple levels to optimize their municipal service and pollution reduction strategies.

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