Increasing the Sustainability of Generation Assets

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ABSTRACT

Electricity production in Canada is nowhere near sustainable. Inexpensive primary input fuels like oil, coal and nuclear fuel have created a false sense of optimum efficiency. Most thermal coal-fired and nuclear-fired generating facilities have an overall conversion efficiency of approximately 33%, based on energy "in" (consumed) and electricity "out" (produced). The potential to increase this overall efficiency depends on finding a suitable use for the vast amount of low-grade heat produced. A district heating system can help recover this low-grade waste heat. Finding potential users for the district-heating network depends on the operating temperature of the heat distribution loop. Most industrial applications require low-pressure streams well above 100C. Commercial and residential applications require supply temperatures of about 50C. The common practice is to use expensive insulated pipes for the heat distribution network (either steam or hot water).

Conventional district heating systems are expensive to install and maintain. The infrastructures costs and service costs are some of the reasons for the limited success. The use of heat pumps at the customer end is an improvement. Heat pumps offer the additional option of summer time cooling using the same distribution loop. In contrast, the district heating steam-loop in Tiverton Ontario at the Bruce Nuclear (BNG) facility is an example of a complex system. The BNG district-heating network has experienced some operational issues over the years. Using a low-temperature water-based distribution network significantly simplifies the installation and the maintenance of the system. Similar technology is being used in remote communities to demonstrate heat recovery from diesel generators. While some heat recovery projects have been installed in remote northern-communities, most applications have failed to demonstrate the full potential of the concept. Distributing low-grade heat and using heat pumps at the customer end is a promising alternative.

Keywords: District Heating, Heat Pumps, Thermal Generation, Heat Recovery

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1.0 Background

1. Central Plant Electricity Production

Typically, the central plants that generate electricity in Canada and the USA do not heat-recover any of their waste heat streams. Not surprising then, that we find North American' s are among the highest per capita energy users in the world (Jacobs, 1993). While we have some regional variations, we depend heavily on fossil fuels to meet our heating and electricity needs (NRCan, 2006).

The opportunity to capitalize on the concept of combined heat and power (CHP) is immense, given our significant need for space heating. Once heat is captured at the CHP facility it needs to be transported to the end-use customer. District heating (DH) is the distribution mechanism to deliver heat to the heating load. The concept of CHP and DH is well established in many Nordic countries in Europe and Asia (Nordvärme, 2006). **Appendix A** provides additional information on conventional district heating systems and their importance in other markets. In Canada, low-cost heating systems, low-cost energy and our large dispersed populations have made DH impractical in most cases. Advances in low-cost plastic pipe and the increase in fossil fuels prices have renewed interest in this country. Several small-scale projects are successfully using CHP for district heating applications (CANMET, 2006). The concepts being presented in this paper can applied to either large-scale or small scale CHP applications. More importantly, global warming and the desire to become more energy efficient is a new driver that is sparking renewed interest in both CHP and DH.

2. Earth Energy Systems (EES)

Taking heat from the ground for space heating and cooling has been around for over 50 years (Lenarduzzi, 1993). Like solar and wind energy this renewable energy source is well developed and proven. Like solar and wind energy, earth-energy systems (EES) have higher 1st costs compared to fossil-fuels alternatives. Integrating CHP and DH with EES could overcome this 1st cost issue.

This paper investigates the benefits of integrating the heat pump delivery system of EES with the waste-heat distributed from a CHP DH loop. The analysis shows a significant drop in the 1st cost for EES making them cost-competitive with the conventional alternatives. In addition, thermal load on the CHP DH loop increases the overall generation efficiency and provides secondary revenue stream for the generation company. To retrofit the CHP DH network into an existing power plant may prove to be cost-prohibitive. Additional research in this area is recommended. However, the need for new electric generation to meet growing load and to replace aging plants presents a golden opportunity to evaluate the benefits of a holistic approach to new central plant designs. CHP DH and EES are three technologies that if integrated correctly could significantly improve of overall energy efficiency.

3. Ground and District Heating Loop Temperatures

Ground temperature ranges from 4 to 12C across most of the populated areas in Canada. To make use of the ground as a heat-source requires a heat pump to upgrade this low-grade ground energy. The terms "ground collector" or "ground heat exchanger" are used to define the network of buried pipes required to perform the heat extraction. This paper calls on the use of combined-heat-and-power (CHP) district-heating (DH) system to replace the ground heat exchanger. Earth energy system (EES) is the term used to describe ground-source heat pumping (GSHP) systems. Prior work with EES has found the cost and complexity of the ground collector to significantly reduce the "market potential" of these renewable systems, especially in dense urban areas. District heating systems, common to Nordic countries, require high population densities to help off-set the high costs of distributing high–grade heat. For this reason, Canada has relatively few CHP/DH schemes. In addition, our need for cooling in the summer makes a heating-only DH network impractical. Thus, the DH network needs to be able to both deliver heat in the winter and reject heat in the summer. Based on these requirements and the temperature limitation of the heat pump technology, the desirable loop operating temperature is ~20C (target temperature). To avoid freezing issues and/or antifreeze issues, the loop would need to operate above 5C. To minimize heat pump limits, the temperatures should be below 30C. Thus, maintaining a loop temperature between 5C and 30C would be the requirement from the central plant. This flexible low-temperature distribution requirement means the DH loop does not need sophisticated insulation to minimize losses over the network, since far-field ground temperatures are normally less than 10C, from the loop temperature. In contrast, a high-temperature hot water or stream DH loop operates at ~100C, requiring significant investment in the piping material and the piping insulation.

The low-temperature district-heating (LTDH) loop design provides two significant benefits. It 1) lowers the cost of the EES system and 2) provides for a low-cost heating and cooling distribution system that can be extended long distances into low-density urban areas. Centralized power plants process enormous amount of water to maintain their Rankin cycle efficiencies. Diverting a modest amount of water for the LTDH loop is not seen as a major obstacle to their normal electricity generation business.

2.0 Low-Temperature District Heating Design

2.1 Insulated vs Un-insulated Distribution Pipe

The main considerations in a hot-water or steam distribution system are construction material, construction costs heat losses and serviceability of the distribution network. A low-temperature distribution system allows the designer to use existing materials and established construction techniques used for water and sewer networks.
The main objectives are to significantly reduce costs for the district heating piping systems, and improve serviceability and reliability.

Plastic, insulated, underground pipe is used to distribute the water at temperatures between 10C and 30C. A heat pump is used to deliver the final space conditioning temperature conditions. The LTDH loop temperature will vary throughout the year based the load requirements, which are dependent on seasonal variation.

Keeping the system operating temperature low reduces losses from the pipes and is more compatible with the heat pump efficient. No special air-handlers are required to extract heat from the district-heating loop, thus simplifying the overall design. In the cooling, mode the loop rejects heat into the district heating loop. An enhancement to the LTDH loop is to incorporate some kind of thermal energy storage system into the overall design. This enhancement is described in greater detail in Appendix B.

3.0 Target Markets for Low-Temperature District-Heating (LTDH)

The target markets listed below are based on a LTDH that can provide a reliable heat sink or heat source over within the target loop temperature of 20C. Secondary heat exchangers may be required and/or heat pumps to deliver the required heating or cooling loads to the target markets.

1. Agricultural soil heating,
2. Aquaculture
3. Irrigation
4. Residential Space Heating and Cooling (includes pool heating and water heating)
5. Commercial Space Heating and Cooling
6. Industrial Space Heating and Cooling
7. Institutional Space Heating and Cooling
8. Multi-Residential Space Heating and Cooling
9. Indoor Sport Centres, including swimming pools, ice rinks, gymnasiums and other recreational facilities.
10. Outdoor pools and stadiums park walkways etc.
11. Snow melting on select roads and/or intersections (winter)

4.0 Analysis of Two Typical Target Markets

1. <u>Heating and Cooling Load Requirement</u>

An economic evaluate of the LTDH concept requires an understanding of the heat and cooling needed by the loads represented in the “Target Markets”, listed above. Detailed analysis of each target market is beyond the scope of this paper. An evaluation of the typical residential and commercial loads should be sufficient to determine the merits of the concept. NOTE: Results for the residential and commercial sectors can be easily applied to the industrial and institution sectors, with respect-to-space conditioning and water heating.

2. <u>Typical Residential Home</u>

An average residential home is assumed to have a heating load of ~10 kW peak, consuming ~20,000 kWh/year. The summertime cooling load is estimated to be 7 kW, rejecting ~10,000 kWh/year of thermal energy and consuming ~3000 kWh/year of electricity.

3. <u>Typical Commercial Building</u>

An average commercial building of 1000 m^2 has a heating load assumed to be 100 kW peak, consuming 200,000 kWh/year. The summertime cooling load is estimated to be ~100 kW, rejecting 150,000 kWh/year.

4. <u>Costs for the End-Use Components</u>

Costs are divided between capital requirements to install the necessary hardware and operating costs. A significant amount of information is available on both capital costs and operating costs of EES, natural gas-fired equipment, electric heating and air-conditioning (ASHRAE, 1999). The information below is presented for the typical residential home and for a typical commercial building of 1000 m2. Scaling these average values is then used to determine the size of the LTDH loop.

Operating costs are derived from the heating loads given above and electricity costs. Electricity costs are assumed to be $0.1/kWh, with natural gas priced at 30% less.

5. Capital Cost for Typical Residential Heating and Cooling Systems

The alternative system for the residential home is a natural-gas furnace and gas water heater with a central air-conditioner. For the typical residential home the capital cost of this system is estimate to be $10,000.

The LTDH heat pump system provides space-heating, water heating with an electric backup plus high-performance central air-conditioning. **Figure 1** is a schematic representation of a typical water-to-air heat pump system. The heat pump system is estimated to cost $5000 and the piping to the LTDH system to cost $2000 for a total of $7000. (NOTE: In most cases installing a ground heat exchanger can cost up to $10,000, for a total of $17,000 for the complete EES).

6. Operating Cost for the Typical Residential Heating and Cooling Systems

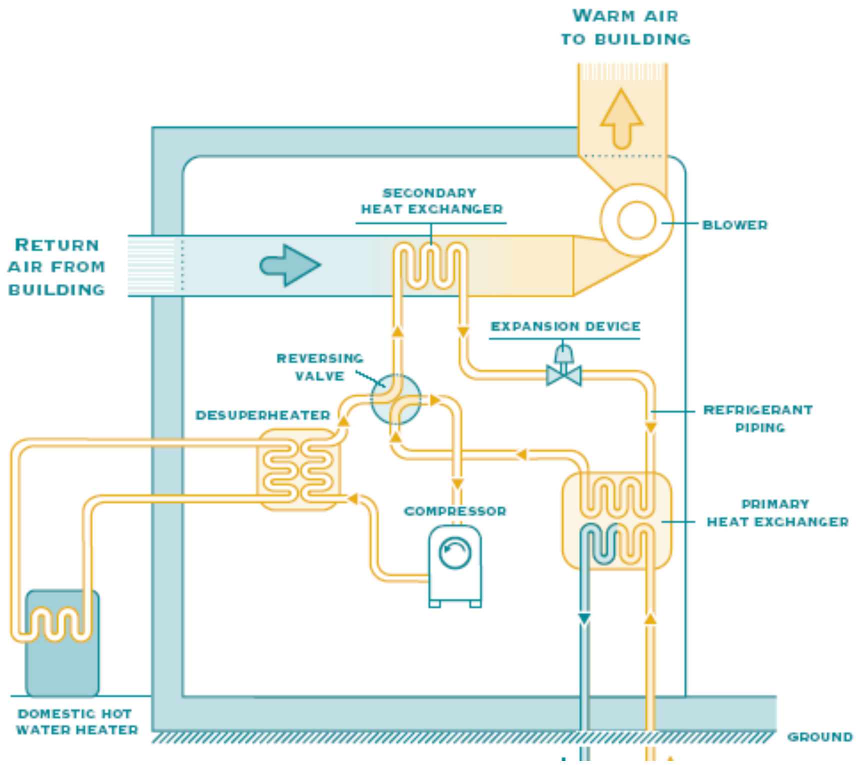
The heating and cooling operating cost for the conventional natural gas system is $1700/year. The heating and cooling operating cost for the LTDH heat pump system is $998/year, for the equivalent heating/cooling effect. Thus, annual savings are $702/home/year, compared to a conventional natural gas system and over $1300/year compared to electric resistance heat.

7. Capital Cost for Typical Commercial Heating and Cooling Systems

For the typical commercial building described above, the alternative conventional system is a packaged rooftop natural-gas furnace/air-conditioning system. The typical costs for such systems are $500/kW. The commercial build has peak consumption of 100 kW. Thus, alternative conventional system cost is $50,000 (for the 1000 m2 commercial building).

The proposed LTDH heat pump system for the commercial building is schematically shown in **Figure 2**. Each of the individual units shown in **Figure 2** would look approximately like the water-to-air unit shown in **Figure 1**. Commercial heat pumps systems cost ~$300/kW. Loop connections are estimated to be $6000 (per 1000 m2 building), for a total capital cost $36,000/building. The capital cost savings for the LTDH system is $14,000 less than the alternative conventional packaged rooftop natural-gas furnace/air-conditioning system.

Figure 1: Typical Schematic for a Residential Water-to-Air Heat Pump System



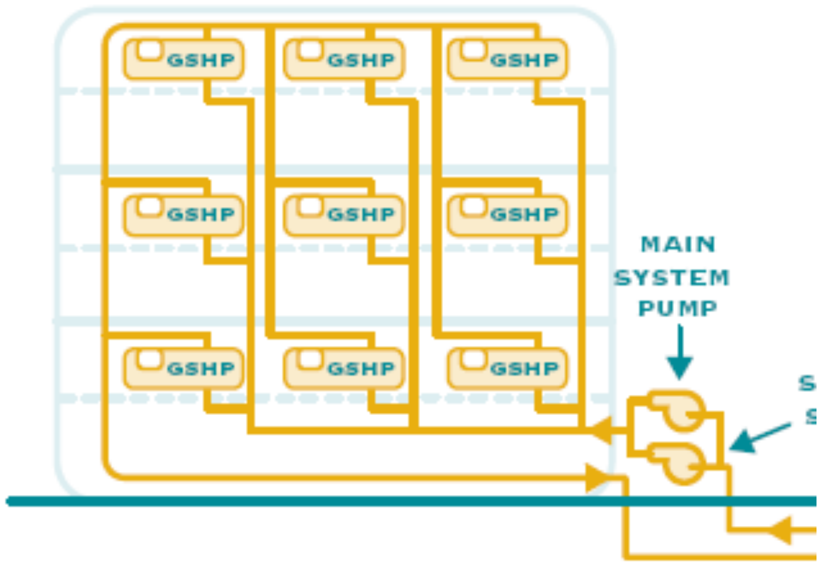
Source: *Commercial Earth Energy Systems- A buyer's Guide,* Natural Resources Canada

A significant cost savings is also realized compared to an earth-energy ground loop system (EES). (NOTE: The cost of installing a ground heat exchanger for the commercial building is estimated to be $30,000.)

8. <u>Operating Cost for the Typical Commercial Heating and Cooling Systems</u>

The estimated heating and cooling operating cost for the conventional system is $19000/year (200 MWh heating and 50 MWh cooling). The heating and cooling operating cost for the LTDH heat pump system is $12,000/year, for an annual savings of $7,000/year. There are also inherent maintenance savings for the heat pump system, as well as longer life span (22 years vs. 15 years for conventional rooftop equipment), in a typical application maintenance savings range between $1.40/ m^2 and $1.65/ m^2 (ASHRAE, 1999).

Figure 2: Schematic Showing the Deployment of Heat Pumps inside a Commercial Building

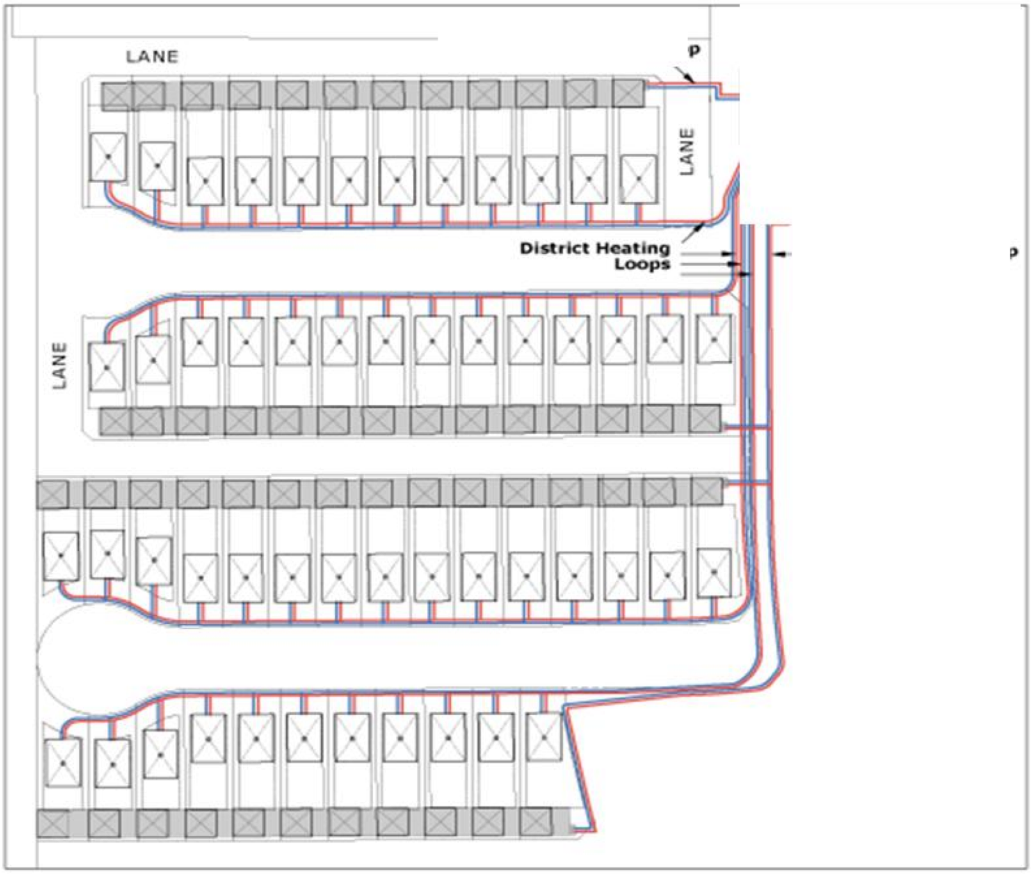


Source: *Commercial Earth Energy Systems- A buyer's Guide,* Natural Resources Canada

Table 1: Operating Cost Savings & Capital Cost Savings

	Operating Costs/year			Capital Costs
	Heating	Cooling	Totals	
Residential Dwellings Load	20000 kWh	3000 kWh		
Conventional Heating/Cooling	$ 1,400	$ 300	$ 1,700	$ 10,000
Heat Pump Costs	$ 571	$ 210	$ 781	$ 5,000
Loop Cost to Utility for Water Fee	$ 143	$ 74	$ 216	$ 2,000
Total Heat Pump Costs	$ 714	$ 284	$ 998	$ 7,000
Savings	$ 686	$ 17	**$ 702**	**$ 3,000**
% Savings	49%	6%	**41%**	**30%**
Commercial Building Load	200,000 kWh	150,000 kWh		
Conventional Heating/Cooling	$ 14,000	$ 5,000	$ 19,000	$ 50,000
Heat Pump Costs	$ 5,714	$ 3,500	$ 9,214	$ 30,000
Loop Cost to Utility for Water Fee	$ 2,000	$ 1,500	$ 3,500	$ 6,000
Total Heat Pump Costs	$ 7,714	$ 5,000	$ 12,714	$ 36,000
Savings	$ 6,286	$ -	**$ 6,286**	**$ 14,000**
% Savings	45%	0%	**33%**	**28%**

Figure 3: Typical LTDH Loop Distribution for a Residential Sub –Division



Source: Drake Landing Solar Community, Natural Resources Canada

9. Summarizing Capital Costs and Operating Costs from the End-user Perspective

From the end-user perspective, a LTDH loop operating at a nominally temperature of 20C can provide residential and commercial customers significant savings compared to convention heating and cooling systems. The calculated capital cost and operating cost savings are summarized in **Table 1**. Missing from the analysis is the cost of the LTDH loop.

5.0 Low-Temperature District Heating (LTDH) Loop

The low-temperature district heating distribution network has three major components to the design, Trenching, Piping and Pumping. Trenching and piping costs are estimated between $200/m to $500/m to bury two 12” HDPE (high density polyethylene) pipes. Included in the cost is a minimal amount of thermal insulation to lower the heat loss from the top of the trench. Typically, central generating facilities are located several kilometers from the potential thermal load. Thus, the assumption is made that the LTDH loop must run 2 km to reach the thermal load. A typical residential load, on a subdivision scale, is shown schematically on **Figure 3**.

The capital cost of the LTDH loop is estimated to be $400,000 per km, including the pump and heat exchanger at the generation plant end. Such a system would have the capacity of supplying over 3000 home and 300 commercial building. The calculated fee per home for supply of the treated water to the heat pumps is $216/

year based on a cost of $10/MWh ($0.01/kWh). For the typical 1000 m2 commercial building the annual cost to the utility for using the LTDH loop is $3500/year. Thus, based on a total LTDH loop cost of $800,000 and a simple payback of 5 years the number of homes need to breakeven could be as low as 400 homes and 20 commercial buildings.

Table 2 shows the number of homes and/or commercial building required to calculate a simple payback of 5 years on the LTDH capital cost. Alternatively, the end-users could afford to capitalize the LTDH loop-expense based on the significant 1st cost savings for the heat pump system. (NOTE: The LTDH pumping cost at the generation plant will vary depending on the number of end-use customers. Pumping costs, water treatment costs and maintenance costs are expected to be much less than conventional DH systems).

Table 2: Expect Utility Revenues from Water Fees – Showing Simple Payback

Table 2: Utility Revenue		# of Home	# of BLDGS	Simple Payback
12" HDPE piping loop Capital Cost	**$ 800,000**	-	-	-
Annual Revenue per Home, Loop-water fees	$ 216	1	0	-
Annual Revenue per Comm Bldg, Loop-water fees	$ 3,500	0	1	-
Annual Utility Revenue from Loop-water fees	$ 160,000	740	0	5.0
Annual Utility Revenue from Loop-water fees	$ 160,000	0	46	5.0
Annual Utility Revenue from Loop-water fees	$ 156,543	400	20	5.1
Annual Utility Revenue from Loop-water fees	$ 169,907	300	30	4.7
Annual Utility Revenue from Loop-water fees	$ 501,450	700	100	1.6

6.0 Conclusions

The low-temperature district heating (LTDH) loop concept can lower electric peak-demand by over 35 percent. Essentially, we get all the benefits of an EES at a capital cost that is less than the conventional system. The savings associated with the operation of earth-energy systems have been well documented at over 50% in heating and over 20% in cooling. The expectations are that the proposed low-temperature district heating (LTDH) system will achieve similar results, while using less capital.

For commercial buildings capital costs are expected to be 28% less than the conventional gas-fired/electric heat/cool units. Similar capital and operating cost savings are expected for industrial and institutional applications.

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Appendix A – Conventional District Heating

"An important method of heating buildings is by hot water produced during electricity production and piped around whole districts, providing both heat and hot water. This extremely efficient use of fossil fuels demands a co-ordination of energy supply with local physical planning, which few countries are institutionally equipped to handle. Where it has been successful, there has usually been local authority involvement in or control of regional energy-services boards, such as in Scandinavia and the USSR. Given the development of these and similar institutional arrangements, the cogeneration of heat and electricity could revolutionize the energy efficiency of buildings worldwide" [Our Common Future World Commission on Environment and Development (The Brundtland Report), Oxford: Oxford University Press, 1987, pp. 200 (IEA, 2004)].

Nordic countries like Finland, Iceland, Norway and Sweden, have all embraced district heating as a viable way to increase overall electricity generation efficiency from less than 40% to over 80% by reclaiming waste heat for space heating. The amount of electricity produced remains unchanged the waste heat is reclaimed by re-circulating hot water or steam.

Nordic cities like Copenhagen in Denmark have used cogeneration of heat and power for more than 50 years, mainly based on supply of steam. While convenience, profitability, and energy conservation have been the major driving forces, protecting the environment is becoming more important. Global warming requires a concerted effort to evaluate not just the cost benefits in terms of energy supply prices, but to also evaluate overall energy efficiency. To achieve these significant efficiency improvements requires a better under understanding of supply and demand and an integration of the delivery mechanism with the producers and end-users. Nordic countries have been most successful when the transmission companies played a pivotal role in the heat distribution system.

Danish Results

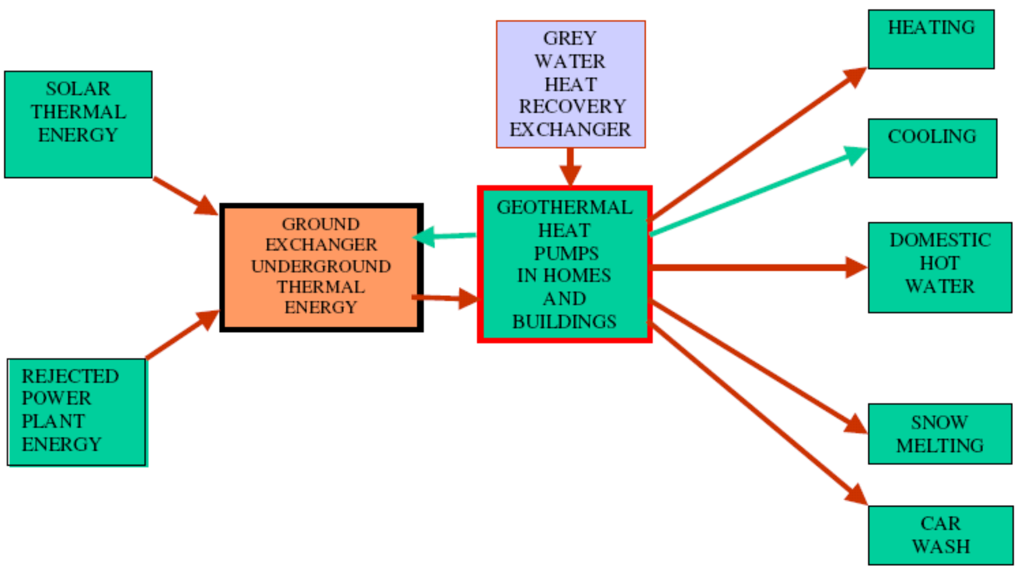
Because of integrated district heating systems, during the last 10 years the SO_2 emissions per TJ energy produced from Danish combined-heat and power (CHP) stations have decreased by 50 %.

Appendix B -- Enhancements: Heat Recovery & Thermal Energy Storage (TES)

The recovery of rejected energy from a generating plant and a LTDH system as described in this document can be further enhanced with the integration of Underground Thermal Energy Storage (UTES). This will allow recovery and storage of summer rejected energy for use during the heating season. Integration with UTES will permit higher overall generating system efficiency; and will allow a larger LTDH system for the same size plant. **Figure 4** shows a schematic representation of the many options that can be accommodate from either a thermal energy storage (TES) system or LTDH loop in combination with TES.

A UTES system is a closed loop ground heat exchanger comprised of many vertical boreholes (150mm dia.) drilled in the earth and loaded with U-tube exchangers that are grouted in place and tied together at the top into a grid pattern. The choice of pipe material will depend on fluid temperature.

Figure 4: Intelligent Heat Recovery and Storage System Flow Diagram



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Robert Mancini has been engaged in the field of Consulting Engineering for his entire career. He has been responsible for many local projects as well as projects in Kuwait, the Bahamas, South Africa and United Arab Emirates. Robert Mancini earned a degree in Mechanical Engineering from the University of Toronto in 1973. He is currently President R. Mancini and Associates Ltd. Consulting Engineers, Bolton, Ontario, Canada. His experience is extensive in the field of heating, ventilating and air conditioning. He has been responsible for the design of over 10000 tons of ground source heat pump systems across North America since 1984. He has served on a committee responsible for the development of CSA 447 "Design and Installation of Commercial Ground Source Heat Pump Systems", CSA 448 “Design and Installation of Earth Energy System” and is a corresponding member of ASHRAE's Ground Source Technical Committee. In addition, has been a member of the Washington based Geothermal Heat Pump Consortium and is one of two consultants chosen for their Design Assistance Program aimed at improving the geothermal heat pump infra structure in the United States.