# District Energy and Co-generation for Public Buildings in Alberta

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*Photo credit – Environmental Design + Construction / April, 2014*


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# *Executive Summary*

*As part of the Government of Alberta's 2016 Climate Leadership Plan, increasing the energy efficiency of the province's built environment is being considered as a method to reduce greenhouse gas (GHG) emissions. Recent studies indicate substantial health and climate benefits for implementing energy-efficient technologies, in addition to the secondary impacts of job creation and innovation. This paper will explore district energy and co-generation as examples of systems that can increase the energy efficiency of the province's built environment. Co-generation and district energy systems can provide both heating and power in one integrated system, and are ideally suited for the Alberta market.*

*Co-generation is the use of a heat engine or power station to generate electricity and useful heat at the same time. The supply of high-temperature heat first drives a gas or steam turbine-powered generator and the resulting low-temperature waste heat is then used for water or space heating. Co-generation is an attractive option for improving building efficiencies because energy is used that may otherwise have been lost. While co-generation can operate at the scale of an individual building, it is most efficient when applied to a network of buildings – this is a system known as district energy. District energy systems produce steam or hot water at a central plant. The steam or hot water is then piped underground to individual buildings for space heating, domestic hot water heating and air conditioning. As a result, individual buildings served by a district energy system don't need their own boilers or furnaces, chillers or air conditioners. Sources of heat can include the fossil fuel options of coal, oil, and natural gas along with renewable options such as solar, wind, biomass and geothermal. For the fossil fuel category, natural gas is the preferred choice as it has the fewest undesirable consequences.*

*While co-generation and district energy systems can be easily incorporated into new construction, they are more suited to districts and campus style applications. Examples include university campuses, hospital complexes where there are multiple buildings, and major airports. District energy is less easily incorporated into existing buildings; however it is possible by adapting heating systems in larger buildings. The design and scale of a district energy system depends on the anticipated energy demand for the specific area – as such, estimating costs for co-generation systems is difficult. Some systems considered in this study range in cost from $3 to $25 million, with a payback between 4 and 10 years. District energy systems can be encouraged through tax incentives, development density bonuses, carbon taxes based on higher energy use, lower permitting costs, or discharge fees.*

*The advantages of co-generation and district energy include increased efficiency, lowered overall GHG emissions, cleaner combustion, and the ability to utilize waste fuel sources. Moreover, these systems provide improved reliability because they are resistant to external risks such as electricity brownouts or blackouts from ice storms, floods and fires. Some of the economic benefits of co-generation and district energy systems include lower heat, fuel and maintenance costs, increased reliability, and reduced peak electricity demand. The main drawbacks and challenges of co-generation and district energy systems are the high first cost, the land disruption required for installation, non-uniform standards among manufacturers of co-*

*generation equipment, and a potentially increased vulnerability to fuel shortages or distribution failure. Moreover, district energy systems require many different stakeholders to work together, which may increase a project's complexity.*

*The use of co-generation and district energy systems can provide considerable long-term cost savings and GHG reductions. These systems are best implemented on new building projects since the components are easier to integrate during the design stage and can provide the best return on investment. The use of co-generation and district energy systems will respond to the Government of Alberta's 2016 Climate Leadership Plan by reducing greenhouse gas emissions, encouraging innovation in the construction and co-generation industries, and increasing public awareness of energy efficient technologies.*

# 1. Introduction

## 1.1 Context

In June 2016, the Government of Alberta introduced a Climate Leadership Plan with a strategy that includes two initiatives: major reductions in greenhouse gas emissions (GHG reduction), and ending pollution from coal-fired electricity generation (GoA, 2016). As part of the implementation of these two initiatives, the use of natural gas as a fuel for electricity generation is a viable energy replacement alternative. The natural gas-fired electricity generation option can contribute to reducing emissions while remaining economical. District energy systems and co-generation often use natural gas as fuel and are strategies that can increase energy efficiency, and are applicable at the scale of individual buildings, a campus of buildings or a whole district. Co-generation is a proven technology that combines the generation of power and the collection and use of waste heat from power generation into one energy efficient process. District energy is the deployment of the energy produced from co-generation at multiple end destinations, instead of limiting it to one facility at the source. This paper will focus primarily on the use and merits of district energy and co-generation in Alberta. The study will examine applications of the technologies for expanded use in the public realm and what constraining or enabling factors need to be considered.

## 1.2 Demand for Improved Energy Efficiency

The 1973-1974 Oil Embargo may have been the first major incident that triggered a re-examination of North America’s dependence on oil and the need to become more efficient users of natural resources. The impact of the embargo led to policy development for domestic energy independence and energy conservation (Office of the Historian, 2016). Volatility in oil pricing in the decades that followed led to periodic re-examination of energy usage and associated efficiencies. In 1993, Leadership in Energy and Environmental Design (LEED) was launched in the United States. LEED brought attention to the need for planning, constructing, maintaining and operating buildings in a more sustainable and resource efficient manner (USGBC, 2016). The Kyoto Protocol (signed in 1997) was the first international agreement that formalized the intentions of nations around the world to begin reducing the emission of greenhouse gases. Energy efficiency is now recognized as one of the most cost effective ways to “improve affordability and reduce the environmental impact of energy production, transmission and use” (AEEA, 2010, p. 3). Energy efficiency is also recognized as “less expensive and easier to deploy than developing new energy supplies” (AEEA, 2010, p. 3). The strategy of district energy (along with co-generation) can greatly increase the efficiency of existing or new energy systems, while reducing the overall need for future power generation in Alberta’s electricity system.

## 1.3 Historical Context

The idea of a district energy system is not new. Distribution of hot water from bath houses to greenhouses in hot water pipes dates back to ancient Rome (Wilson, 2007). The ancient city of Hierapolis in western Turkey also had mineral baths fueled by hot spring water fed by aqueducts (Padfield, 2015). The French village of Chaudes-Aigues in Cantal has used hot spring water continuously since the 14th century, originally using wooden pipes to distribute the water. In North America, the first district heating system dates to 1853 for the U.S. Naval Academy in Annapolis, Maryland (Wilson, 2007). The first steam heating system to serve a downtown community was in Lockport, New York in 1877.

Later, in 1906, Thomas Edison built a downtown power plant in Philadelphia. He determined that the plant would not be profitable unless he could sell the waste heat. He was successful in selling the heat to nearby Jefferson University Hospital. The combination of power production and the capturing and using of waste heat resulted in the first combined heat and power (CHP) system. There are currently over 6000 district energy systems in North America, many of them as part of universities or major hospital complexes (Wilson, 2007).

*Figure 1 – District heating system plant in Baden-Baden, Germany burns wood chips to provide 5.3MW of electricity and 3.5MW of hot water - Photo credit – Google Images*

## 1.4 Understanding District Energy

There are three main components to a district energy system: a source of thermal energy, a piping network to distribute the energy, and a mechanism for utilizing that energy in the building (Wilson, 2007). The source of heat is often a fossil fuel such as coal, natural gas, oil or wood chips. Since the mandate of this study is to examine improved energy efficiency while reducing GHG emissions, the option of natural gas becomes the preferred choice as it has the fewest undesirable consequences. The second component of a district energy system is the distribution of the energy. While steam or hot water can be circulated in piping, hot water is now most common. In older systems involving steam, there are higher costs for the piping, problems with condensate build-up and greater heat loss.

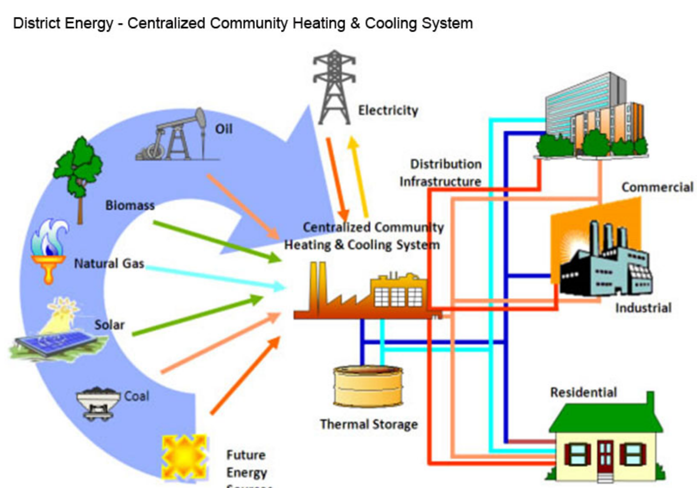



*Figure 2 – Schematic showing typical district energy system – Possible heat sources are shown on the left; possible applications on the right. Photo credit – Google Images*

The final component is a mechanism for using the heat in the building. Often, the heat from the distributed district energy piping flows through a heat exchanger that heats a hot water tank. From there, the heated water can directly go to building baseboard radiators, overhead ceiling radiant panels or to fan-coils in the air ducts when forced air heating systems are used.

## 1.5 Understanding Co-generation

Co-generation can be associated with a district energy system or it can be a stand-alone energy source for an individual building. The main distinguishing feature about co-generation is that it produces both heat and power. The practice of combining both heat and power is referred to by the shorter term CHP. If cooling is also provided, this is technically tri-generation and the acronym is CCHP.

With CHP, the production of power is the main goal and the capture and use of heat is a by-product. When cooling is needed, electricity can be used to chill the water. This method requires the redundancy of both heating and cooling distribution piping. A more economical option is to distribute only heat within the building and use thermally activated absorption or adsorption chillers to provide the cooling.

CHP is an attractive option for improving building efficiencies because energy is used that may otherwise have been lost. Natural gas fired power generation on its own is often only 50-60% efficient (Wilson, 2007) while the overall system efficiency can be greatly increased by also using the waste heat.

**Case Study #1 – Example of District Energy**
**Strathcona County's Community Energy Centre**

**LEED** - The Community Energy Centre was designed and constructed to achieve LEED® Silver certification. It became the first LEED® certified building in Strathcona County, Alberta.
**Building Features** –
Building area: 305m2 (3,300 s.f.)
Architectural design to match Centre in the Park
Attractive landscaping (with all existing trees retained)
**Environmental Benefits** –
Boilers in the Energy Centre use natural gas to heat hot water. The hot water is delivered by underground insulated piping to each building. The central boiler system eliminates the need for individual boilers. Each building connected to the system receives the energy through an energy transfer station (or plate heat exchanger). The cooled water returns to the Energy Centre to be re-heated and re-distributed. The highly efficient system reduces greenhouse gases by 18% per year compared with a conventional heating system.
**Buildings that are connected to the system** –
County Hall, Festival Place, the Kinsmen Leisure Centre (pool), Sherwood Park Arena and Sports Centre and the recreation office. Future municipal and commercial buildings in the area will also be connected to the Energy Centre.

*Figure 3 – Completed Community Energy Centre building – delivers heat to a number of buildings in the centre of Sherwood Park, Alberta from a central source. Built on a brownfield site adjacent to Sherwood Park Mall. Photo credit – Strathcona County (Strathcona, 2016).*

### 1.6 Synergies between District Energy and Co-generation

While CHP can operate at the scale of an individual building, it is most efficient when combined with district energy systems. With the advancement of district energy systems, CHP and CCHP systems have become a core solution to improving energy efficiency and reducing greenhouse gas emissions (GHG) (Liu et al., 2014). Conventional systems are of low efficiency since there is often surplus heat produced that goes unused. With CHP, “most of the electric and heating demands are provided simultaneously by a prime mover together with a heat recovery system” (p. 2) and a heat storage system. Refer to Figure 4.

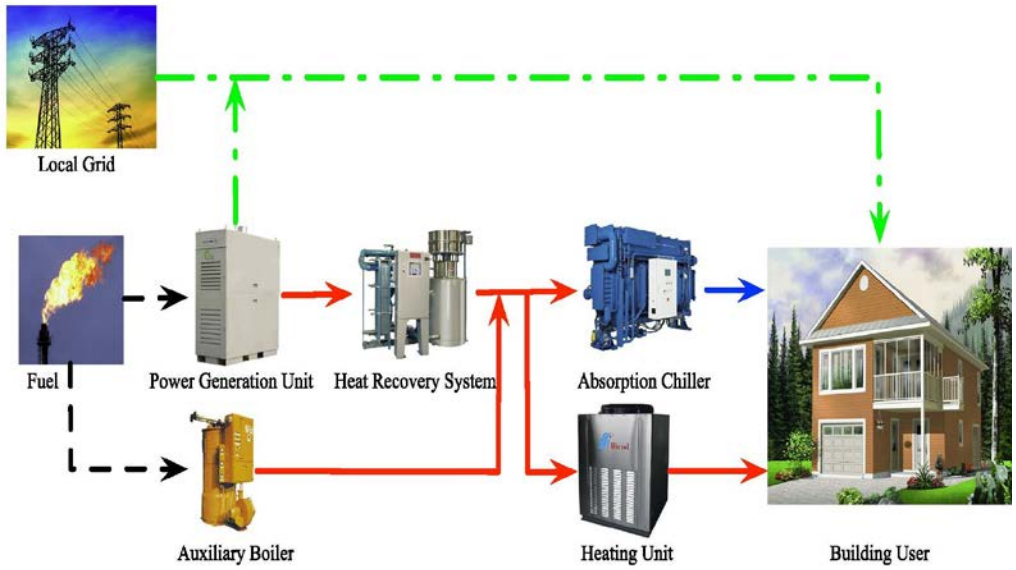



*Figure 4 – Schematic showing typical parts of a CCHP system – Photo credit – (Liu et al., 2014, p. 2)*

Compared to a traditional single purpose system, the advantages of CHP and CCHP are several. A power generation unit (PGU) alone may have an efficiency as low as 30%. By implementing the heat recovery feature, the CCHP system can improve the efficiency to as high as 88% (p. 2). A second advantage is the lowered overall GHG. Electricity from the grid, that is high in fossil-fired (often coal fired) type power, is replaced by the more efficient energy alternative. A final advantage is that the CCHP system is reliable and at a reasonable price. It is a resilient system that is resistant to external risks such as electricity brownouts or blackouts from ice storms, floods and fires.

## 2. Planning and Technical Considerations

### 2.1 Alberta’s Climate and Geography

Alberta is located between 49 and 60 degrees latitude and is mostly in climate zone 7, a zone that is described as very cold. Overall, the requirement for cooling in Alberta is much less than for heating. However, natural day-time heat build-up in the summer and shoulder seasons does make it necessary to provide cooling in public buildings. CCHP systems can provide both heating and power, along with low-cost cooling in one integrated system, and are ideally suited for the Alberta market.

## 2.2 Fuel Sources for District Energy and Greenhouse Gas Emissions

Fossil fuel combustion sources can include lignite (a low grade coal), coal, oil, and natural gas. Other potential energy sources include renewables such as solar PV, wind, biomass and geothermal. Any of the renewable sources will result in very low GHG emissions. Except for biomass, these sources can all generate power directly and efficiently. Among the fossil fuel options, natural gas is the best option as it is the cleanest burning with the lowest GHG output. Refer to Table 1 for comparisons. Biomass and geothermal options will be discussed in subsequent sections of this report.

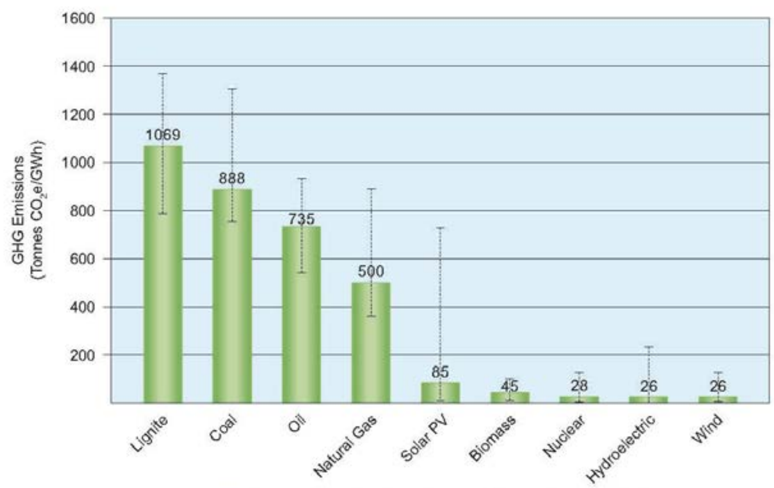



*Table 1 – Lifecycle GHG Emissions Intensity of Electricity Generation Methods – Photo credit – World Nuclear Association (WNA)*

## 2.3 Biomass

Biomass power is considered carbon neutral because the fuel source is generated from “organic waste that would otherwise be dumped in landfills, openly burned, or left as fodder for forest fires” (ReEnergy, 2016). Sources of fuel could include waste from tree pruning, lumber cutting and various other recycling materials. Prime opportunities for a power plant using biomass fuel are locations in proximity to a lumber mill, a pulp mill or in regions where there has been major loss of forest because of pine beetle infestation. Refer to Figure 5.

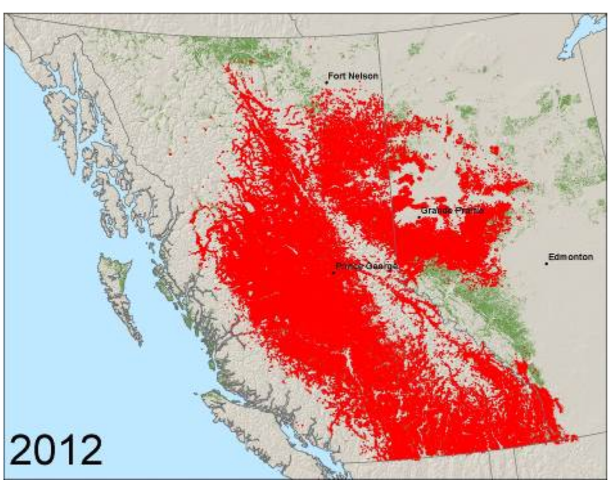
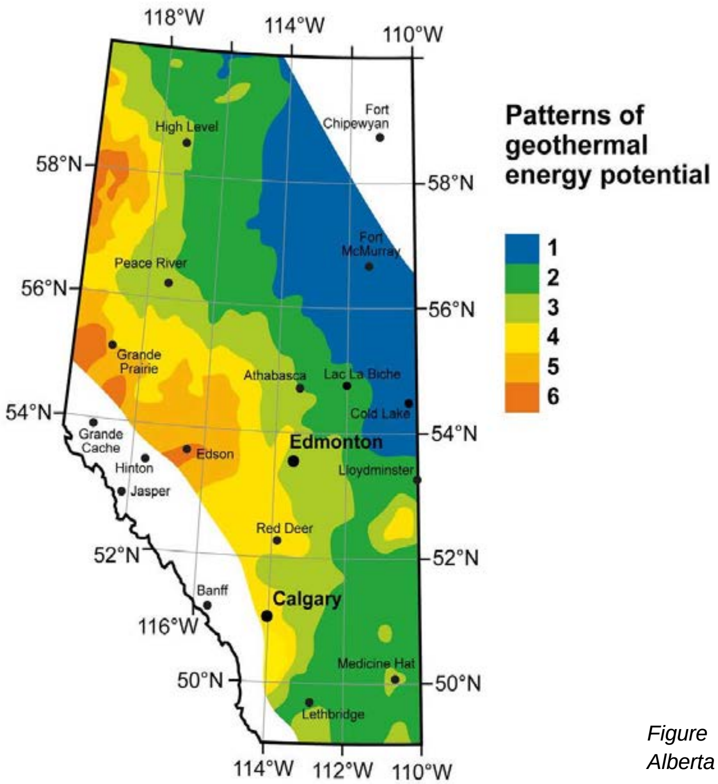



*Figure 5 – Mountain Pine Beetle Displacement – Photo credit – Natural Resources Canada*

## 2.4 Geothermal

Where there is a close source of higher temperature geothermal energy, it is economical to capture this energy and distribute it through district energy systems. In most systems, water is pumped underground where it is heated by the ground and pumped back out for distribution,




While the use of geothermal energy for district heating has been increasing in recent decades, the best potential is in geologically active areas with higher subsurface temperatures (Wilson, 2007). In Alberta, Figure 6 shows the regions with best potential are in the western half of the province, particularly around Edson and Grande Prairie. A study at the University of Calgary (Majorowicz et al., 2014) indicates that heat generated from deep geothermal sources "can save 30MT $CO_2$ per year" (p. 548). By comparison, oilsands operations generate 40MT $CO_2$ per year.

*Figure 6 – Patterns of Geothermal Energy Potential in Alberta – Photo credit – (Majorowicz & Moore, 2014, p. 544)*

## 2.5 Regional Planning

Strong regional planning is key to successful district energy systems. If master planning is done for a region or neighbourhood, efficiencies can be planned in advance to include a reduction in space requirements for mechanical equipment, shared costs for a central plant and the combining of service trenches. Utility companies may be willing to share the cost of trenching if they can locate their cabling in a protected service corridor. Optimal sizing and insulating of piping can be determined with efficiencies realized through larger scales. Although there will be a cost for a building owner to "hook-up" to the system, much like hooking up to water and sewer services, there are capital cost savings of less equipment in the building. If jurisdictions provide incentives for district systems, there may be lower taxes and permitting fees.

Many of the best opportunities for large-scale master planning are occurring today on sites such as old military bases or municipal airports. A local example is Edmonton's Blatchford Field where a district energy strategy is being contemplated. In Philadelphia, the re-planning of the

Navy Yard is a progressive example of a site where large-scale co-operation allowed for the incorporation of a regional power grid and the reduction of carbon emissions by 52%.

**Case Study #2 – Example of Biomass Energy**
**<u>Växjö, Sweden: Wood Chip Fired CHP Plant</u>**

**Växjö, Sweden** – Is often called Europe's greenest city.
Municipality area: 85,000 people; Urban core: 60,000 people.
VEAB's CHP plant provides 29,000 customers with electricity and 6,500 with heat. The city has a goal of becoming fossil-fuel-free by 2030. So far, they have reduced emissions per resident by 41% (from 1993 baseline) and renewable energy use is now 60%.

**Växjö CHP features** –
There are four boilers in the plant, including back-up boilers that burn oil. 95% of the energy output is currently from wood chips that are sourced from an 80km. radius of the plant. The largest boiler can produce 38MW of electricity and 66MW of thermal energy. See Figure 7.

**Background** –
Växjö's interest in sustainability dates back to the 1960's when the surrounding lakes were heavily polluted. The fish were inedible and the water was unsafe for swimming. The city decided to do something about it and launched a major clean-up that was very successful. In 1992, a number of city leaders attended and were inspired by Rio Earth Summit. Following this conference a resolution was adopted that started them on their current path. Although they now have a biogas fuelling station at the sewage plant, transportation challenges will be their biggest remaining hurdle (Wilson, Apr., 2013).


*Figure 7 – Växjö, Sweden's Combined Heat and Power Plant – Photo credit – Google images.*

## 2.6 Life Cycle Impacts

Several studies that compare cogeneration (CHP) or tri-generation systems (CCHP) to conventional systems that produce power and heat separately, acknowledge that the combined systems can raise the efficiency anywhere from 60% to 90% or more (Çomakli et al., 2015). A lowering of fuel used for producing energy will result not only in a reduction of running costs but in a reduction of emissions that contribute to greenhouse gases (GHG). Along with reducing air pollution this efficiency also "increases power reliability and quality, reduces grid congestion and avoids distribution losses" (p. 2095).

The side benefits of district energy and cogeneration are very difficult to factor into life-cycle analysis (LCA) calculations, particularly due to the variability of cogeneration systems. In the UK, researchers (Kelly et al., 2015) confirm with a case study for an industrial CHP application, that there is indeed a “lowering of associated energy and carbon impacts” (Kelly et al., 2015, p. 812). They worry, however, that as the electrical grid becomes successful in reducing carbon intensity, that CHP will lose its current competitive edge. A study at the University of Pittsburgh (Osman & Ries, 2006) concludes that gas-fired cogenerations systems allow buildings to generate their own electricity while utilizing the “wasted thermal energy for a variety of purposes, such as space and water heating as well as cooling with absorption chillers” (p. 269). Refer to Figure 8. Refer also to section 5.2 for related aspect of Life Cycle Assessment (LCA).

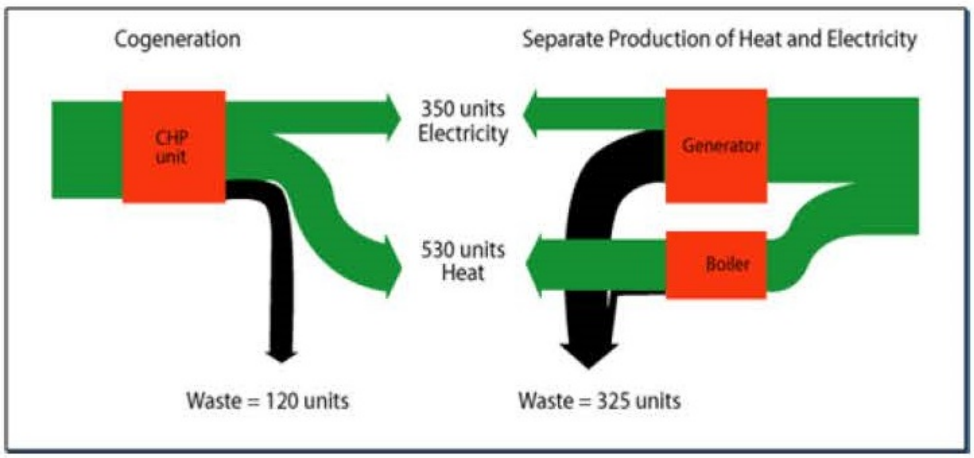



*Figure 8 – The Efficiency Benefits of Cogeneration – Photo credit – WADE*

## 2.7 Other Constraining and Enabling Factors

Generally, the main challenges to wider scale deployment are: the high initial up-front capital investment, connecting to utility grids as a back-up, and non-uniform standards among manufacturers of CHP and CCHP equipment (Liu et al., 2014, p. 16). Moreover, implementing district heating systems require many different stakeholders to work together. The consultation and cooperation required to manage these type of projects can result in increased complexity and negotiation challenges.

## 2.8 Legal Issues

For some properties, it may be necessary to purchase and establish an easement on an adjacent property, if there are utility lines crossing property boundaries. For shared systems, agreements similar to condominium bylaws may need to be established. A report by the Association for Decentralized Energy in the U.K. suggests that there are a wide range of legal frameworks needed including consumer issues such as “access to land, continuity of supply, and consumer repayment (ADE, 2012).

# 3. Current Technologies

## 3.1 Prime Movers

A prime mover is defined as "a machine that transforms energy from thermal, electrical or pressure form to mechanical form" (Liu et al., 2014, p. 3) and typically involves an engine or turbine as the heart of the energy system. Some types of prime movers include reciprocating internal combustion engines, combustion turbines, steam turbines, micro-turbines, stirling engines and fuel cells. Among the most popular prime movers for district energy systems are the micro-turbines, noted for their low level of GHG emissions, flexible fuel options and compact size. Refer to Figure 9 for an example of a micro-turbine. Refer also to Table 2 for a comparison of different types of prime movers.

*Figure 9 – Example of Micro-turbine – Capstone C200 – Power output of 190kW – Photo Credit - Capstone*

| Prime Mover | Size (kWh) | Pros | Cons | Emissions | Preferences and Applications |
|---|---|---|---|---|---|
| | | | | | |
| IC Engine | 10-5000 | -Low capital cost<br>-Quick start<br>-Good load following<br>-High partial efficiency<br>-High reliability | -Regular maintenance required | -High $NO_X$ using diesel<br>-Natural gas preferred | -Working with absorption/electric chiller<br>-Small-to-medium scale |
| Combustion turbine | 500-250,000 | -High quality exhaust heat | -Unacceptable low partial efficiency | -$NO_X$, 25ppm<br>-CO, 10-50ppm | -Applications with huge amount of thermal need large-scale |
| Steam turbine | 50-500,000 | -Flexible fuel | -Low electric efficiency<br>-Long start-up | -Depends on fuel | -Electricity as by-product, thermal need preferred<br>-Large-scale |
| Micro-turbine | 1-1000 | -Flexible fuel<br>-High rotation speed<br>-Compact size<br>-Less moving parts<br>-Lower noise | -High capital cost<br>-Low electric efficiency<br>-Efficiency sensitive to ambient conditions | -$NO_X$, <10ppm | -Distributed energy system<br>-Micro-to-small scale |
| Stirling engine | Up to 100 | -More safe and silent<br>-Flexible fuel<br>-Long service time<br>-Can be solar driven | -High capital cost<br>-Power output hard to tune | -Less than IC engine | -Solar driven<br>-Small scale |
| Fuel cell | 0.5-1200 | -Operate quietly<br>-Higher reliability than IC engine<br>-High efficiency | -Energy consumption and GHG emissions due to hydrogen producing | -Extremely low | -Micro-to-medium scale |

*Table 2 – Comparisons among different prime movers – (Liu et al., 2014, p.6)*

## 3.2 Thermally Activated Technologies

In conventional self-generation systems, about two-thirds of the fuel used to generate electricity is wasted. The wasted heat can be captured and used for space heating and cooling and is the main benefit and efficiency that can be gained by expanding single-purpose self-generation into co-generation and/or tri-generation systems. A heat recovery system (Figure 4) is used to harness the excess heat and direct it to other units as needed for either heating or cooling. On the cooling side, there are three ways that the heat can be re-processed into cooling using thermally activated technologies. These include: absorption chillers, adsorption chillers and desiccant dehumidifiers. Absorption chillers use heat to provide the energy for the refrigerants (in a chemical process) to induce the pressure difference needed for the cooling process, whereas conventional chillers use electricity and a mechanical compression process to provide the same pressure difference. Adsorption is similar to absorption in that both processes involve using the energy from heat to chemically induce a pressure difference. With absorption, the process takes place throughout the bulk of the liquid whereas with adsorption, it is a surface phenomenon. Desiccant dehumidifiers operate using the adsorption principle. The process uses a humidity absorbing material called the desiccant. These systems are more efficient and effective because there are no moving parts and in northern climates, they can operate at lower temperatures compared to conventional compressor type humidifiers. Absorption chillers are the most common and have been widely developed due to their advantages that include: low noise, no moving parts, low GHG emissions, and adaptability to low quality heat sources.

## 3.3 System Configurations

The anticipated energy demand for the specific area is the main consideration that will drive the design and scale of the CCHP system to be developed. Economical, efficient, and low-emitting systems are possible with the right selection of a prime mover and with an optimum configuration. Refer to Table 3 for comparisons among different system configurations.

| **Configuration** | **Size** | **Preferences and Applications** |
|---|---|---|
| | | |
| Micro-scale | <20kW | -Distributed energy systems |
| Small scale | 20kW - 1MW | -Supermarkets, retail stores, hospitals, office buildings, and university campuses |
| Medium scale | 1MW – 10MW | -Large factories, hospitals and schools |
| Large scale | >10MW | -Large industries<br>-Waste heat can be used for universities and districts with higher densities |

*Table 3 – Comparisons among different system configurations – (Liu et al., 2014, p.6)*

## 3.4 Optimizations and Sizing

Once a basic configuration is determined, the next step is to optimize and “right-size” the design. A common miscalculation that can lead to inefficiencies is to size the system for peak-loading. A better approach is to size the system for the average energy demand, while relying on the connection to the electrical grid for handling peak demand. However, the size should not be too small as that could lead to negative perceptions about the appropriateness of the system.

The Goldilocks syndrome of right sizing (not too hot, not too cold) is the key to efficiency and can be achieved by using energy modelling. The modelling can also be used to fine-tune the energy system strategy and energy use reduction efforts.

**Case Study #3 – Example of District Energy System**
**University of Alberta: North Campus**

**Utility System** – "The University of Alberta owns and operates one of the largest campus district energy systems in North America. This system is anchored by the university's Heating and Cooling plants and supplies services to the university as well as the University of Alberta Hospital, the Stollery Children's Hospital, the Cross Cancer Institute, the Jubilee Auditorium, Canadian Blood Services and other small entities" (UofA, 2016).

**Heating Plant** –
The Heating Plant is located on the southwest area of the campus and has a capacity of 650 tonnes/hour steam. The plant was first built in 1959 with later additions of boilers and other equipment as building extensions occurred. Major additions included a 13.3 MW back pressure steam turbine generator in 1994 and a 26.4 MW condensing steam turbine generator in 2000.

**Cooling Plant** –
The Cooling Plant was built in phases from 1968 to 1983. The plant has a number of chillers varying in size from 2,000 to 3,500 tons. All of the machines use electric centrifugal compressors. Water from the North Saskatchewan River is used for condensing purposes. This water makes the plant very efficient as it can operate in free-cooling mode during the winter months because of the low water temperature. This significantly reduces costs as the electric driven compressors do not have to run to produce the cooling.


*Figure 10 – University of Alberta's North Heating and Cooling Plant (above) and mechanical distribution network in underground utility corridors (below) – Photo credits – University of Alberta.*

# 4. Feasibility and Applications

## 4.1 New Construction

While district energy and co-generation systems can be easily incorporated into new construction, they are best suited to districts and campus style applications. Examples include university campuses, hospital complexes where there are multiple buildings, and major airports. New districts such as Edmonton's Blatchford or the Quarters Downtown Community (figure 11) are prime examples of where the methodology can be optimally applied. Industrial cogeneration applications are possibly the largest application that can take advantage of available technology. These include the northern Alberta oil sands projects, other oil and gas sites, forestry, pulp and paper, and agriculture.

*Figure 11 – Proposed Boyle Renaissance area in the Quarters, Edmonton – Photo credit - www.districtenergy.org*

## 4.2 Advancing District Energy Systems in Existing Buildings

District energy and co-generation systems are less easily incorporated into existing buildings because of the disruption to services and the challenges of changeovers. However, many larger buildings already have existing hot water heating systems with the end distribution in the needed configuration of either baseboard radiators or overhead radiant ceiling panels. These are easily adaptable to district energy hook-ups. Forced air systems can also be adapted by placing heating coils in existing ductwork or by adding a heat exchanger. A simple strategy to facilitate adaption and make buildings "district energy ready" is to locate mechanical rooms on the street side of the building for a shorter utility connection.

District energy systems can be encouraged through tax incentives or development density bonuses. Other strategies that would incentivize district energy are carbon taxes based on higher energy use, lower permitting costs for district energy, or discharge fees for heating equipment in buildings (based on sizing of the equipment). For areas where district energy is available, hook-ups could be mandatory just as water and sewer hook-ups are required as part of permitting (Wilson, 2007, p. 16). CHP has seen success in larger industrial projects such as the oil sands where there are currently 16 operational projects (Districtenergy, 2013). For remote industrial projects that have high power needs, cogeneration can play an important part in reducing energy needs along with lowering emissions outputs. It is also cost effective when the efficiency of the systems are factored in along with the reduced transmission costs of conventional power.

# 5. Cost Considerations

## 5.1 First Costs

Definitive costs for CCHP systems are difficult to determine accurately because there are so many variables with each system. Researchers at the University of Victoria (Liu et al., 2014) do shed some light on various sized systems. They found that smaller **micro-scale systems**, provide a good economic efficiency with an average payback of only 2.7 years (p. 10). For **small scale systems** (of 20kW-1MW), researchers provide an example of a system containing 10 micro-turbines and 1 absorption chiller that in total cost $2.5M and whose payback was 6-8 years (p.10). For **medium scale systems**, power output ranges from 1MW-10MW. For a small college in Elgin, Illinois, a 4.3MW CCHP system serves the power, heating and cooling needs. Built in 2 phases, the total cost is $3.7M. The 2nd phase saves enough annually to result in a 4-year payback (p.11). **Large scale systems** of over 10MW are normally intended to serve large factories, hospitals or universities. A new system at the University of California in San Diego has a capital cost of $25.7 million and is estimated to be paid back in 10 years. Overall variation in costing is illustrated by a final example of a system costing $36M and is estimated to have only a 5.1 year payback (p.11-12).

**Case Study #4 – Example of District Energy - Calgary's Downtown District Energy Centre**

The City of Calgary set out in 2006 to reduce greenhouse gas emission levels by 50% by 2050. The glass enclosed building on 9 Avenue and 4 Street SE houses the central boilers that deliver hot water through an underground network of pipes to downtown offices and residential buildings.

**Six Features about the Downtown District Energy Centre** –

Not a new idea – Idea goes back to Roman times where similar process was used to heat greenhouses and baths.

Design is functional – Energy Centre produces fewer emissions than conventional heating systems.

Design is recognized – The design earned LEED® Silver certification for its building strategies and practices.

It's a popular idea - There are about 130 district energy plants across Canada, mostly at hospitals and university campuses.

It's a big idea - System is capable of heating over 10million square feet of building space.

It's catching on – Many buildings in downtown Calgary are connected to the centre with more on the way.

*Figure 12 – Calgary's Downtown Energy Centre at 9 Ave. & 4 Str. SE. - Photo credit – Enmac Corporation*

**Buildings connected to the system** -
The City of Calgary's Municipal Building was the facility's first customer, signing on in 2010. Bow Valley College's new south campus signed on and became Calgary's first building to not have a conventional boiler system. Other customers include Calgary's Municipal Land Corporation's new home (the Hillier Block Building) in the East Village, City Hall, the Alberta Trade Centre, the Andrew Davison Building and the National Music Centre. The system is capable of supplying up to 10 million square feet of new and existing residential and commercial space (ENMAX, 2016).

None of the payback savings factor in the advantages of social sustainability: improved health and a cleaner environment from smaller footprints and lower emissions, where society can expect to significantly benefit from greater use of district energy and co-generation systems.

## 5.2 Life Cycle Assessment (LCA)

Life Cycle Assessment (LCA) is "a way to account for the environmental burden of a given product or service across its whole lifetime, from material extraction to manufacture to use to disposal or from 'cradle to grave' "(Kelly et al., 2014). This definition provides a generic outline of the phases involved in the life cycle of CCHP systems. For extraction, because of the variable nature of the composition and complexity of systems, it is difficult to make assumptions for the sourcing of the major equipment that makes up CCHP systems. Similarly, it is difficult to determine the amount of emissions expended during manufacturing. Studying a manufacturer's website will give clues about their process emissions and how they measure up in their corporate social responsibility. Generally, sourcing products from closer to home and using lower carbon transportation such as rail or ship will lower the overall carbon footprint and resource use. For design life, researchers (Kelly et al., 2014, p. 815) generalize an assumed life of 30 years. This life span is used as a basis for calculating return on investment in the next section. At the decommissioning and disposal stage, CCHP systems are favorable because most materials (including many valuable metals) can be salvaged for re-cycling.

## 5.3 Return on Investment (ROI)

Using the estimates from First Costs above for several given scenarios, per project savings and return on investments can be determined. The results for the given examples are as follows (assuming that cogeneration systems have an expected trouble-free design life of 30 years):

**Micro-scale systems -**

**Payback** = Investment / Savings per year = $ 1.0M / $ 370K per year = **2.7 years**.

**ROI** (in percentage) = $\frac{\text{[Gain from investment – Cost of investment] x 100\%}}{\text{Cost of investment}}$

Or equal to $\frac{\text{[Savings over the life of the change – Capital cost of the change] x 100\%}}{\text{Capital cost of the change.}}$

Therefore, ROI = $\frac{\text{[30 years x \$370K/year] – [\$ 1.0M] x 100}}{\text{\$ 1.0M}}$ = 1,010% (a positive return)

**Return on investment** for the provided scenario = **1,010%**.

**Small-scale systems -**

**Payback** = Investment / Savings per year = $ 2.5M / $ 312K per year = **8.0 years**.

**ROI** (in percentage) = $\frac{\text{[Gain from investment – Cost of investment] x 100\%}}{\text{Cost of investment}}$

Or equal to [Savings over the life of the change – Capital cost of the change] x 100%
Capital cost of the change.

Therefore, ROI = [30 years x $312K/year] – [$ 2.5M] x 100 = 274% (a positive return)
$ 2.5M

**Return on investment** for the provided scenario = **274%**.

**Medium-scale systems -**

**Payback** = Investment / Savings per year = $ 1.2M / $ 300K per year = **4.0 years**.

**ROI** (in percentage) = [Gain from investment – Cost of investment] x 100%
Cost of investment

Or equal to [Savings over the life of the change – Capital cost of the change] x 100%
Capital cost of the change.

Therefore, ROI = [30 years x $300K/year] – [$ 1.2M] x 100 = 650% (a positive return)
$ 1.2M

**Return on investment** for the provided scenario = **650%**.

**Large-scale systems – Example A**

**Payback** = Investment / Savings per year = $ 25.7M / $ 2.57M per year = **10.0 years**.

**ROI** (in percentage) = [Gain from investment – Cost of investment] x 100%
Cost of investment

Or equal to [Savings over the life of the change – Capital cost of the change] x 100%
Capital cost of the change.

Therefore, ROI = [30 years x $2.57M/year] – [$ 25.7M] x 100 = 200% (a positive return)
$ 25.7M

**Return on investment** for the provided scenario = **200%**.

**Large-scale systems – Example B**

**Payback** = Investment / Savings per year = $ 36.0M / $ 7.06M per year = **5.1 years**.

**ROI** (in percentage) = [Gain from investment – Cost of investment] x 100%
Cost of investment

Or equal to [Savings over the life of the change – Capital cost of the change] x 488%
Capital cost of the change.

Therefore, ROI = [30 years x $7.06/year] – [$ 36.0M] x 100 = 488% (a positive return)
$ 36.0M
**Return on investment** for the provided scenario = **488%**.

**Case Study #5 – Example of District Energy System**
**Philadelphia's Navy Yard**

**Background** – "The Philadelphia Naval Shipyard, which had its origin in 1776 and relocated to the present site at the confluence of the Schuylkill and Delaware Rivers in 1871, was the (U.S.) nation's first naval facility. Fifty-three naval ships were built here, including the famed New Jersey and Wisconsin battleships in World War II; some 574 ships were repaired here. At its peak, in the 1940's the shipyard employed 40,000 people" (Wilson, Nov., 2013).

**New life for an old military base** – The Navy Yard was largely shut down by 1995. The City of Philadelphia along with some major partners took over the site. It received a major boost in 2006 when Urban Outfitters moved their headquarters to the site into 4 renovated buildings. Their buildings demonstrate a "strong example of adaptive reuse and green rehabilitation tied to historic preservation".

**Master planning at its best** –

Many of the most progressive development projects today are occurring on sites where large-scale master planning is possible. Some of the features of the Navy Yard include the following:

- Mixed-use inner city development with 6.2 million s.f. of office and research space, 5.7 million s.f. of industrial space, and 1,018 housing units planned.
- Continued job creation planned with 36,000 jobs planned for full buildout.
- Nine of eleven new buildings on the site are LEED certified.
- An extensive network of pedestrian walkways, bicycle lanes, and bicycle paths throughout the Navy Yard.
- Public transit links to nearby Philadelphia International Airport and downtown.
- An extensive collection of stormwater features to manage water on site and minimize run-off.
- Extensive open space, community gathering areas, buffer zones and public linkages to neighbourhoods.
- District power generations systems including innovative fuel cell systems that reduce carbon emissions by 52% and the creation of a microgrid that can be isolated from regional power.




*Figure 13 – (clockwise) Navy Yard urban planning, Urban Outfitters headquarters, exterior of restored historic building, Urban Outfitters interior, Navy Yard aerial view – Photo Credit – Google images.*

# 6. Outcomes

## 6.1 Environmental Benefits

Several environmental benefits of district energy systems and CCHP that are noted in this report, along with contextual benefits are summarized in the following table (Table 4).

| Environmental Benefits | |
|---|---|
| Cleaner combustion | Producing heat at large, central facilities (using large boilers or CCHP plants) is cleaner, per unit of heat delivered, than operating smaller boilers at individual buildings. |
| Higher efficiencies | Larger, central boilers generally operate at higher efficiency than individual systems in buildings. With central heat production, it is common to install several boilers so that individual units can be brought on as needed, and they operate at full load for highest efficiency. Boilers at individual buildings (residential or commercial) are sized to meet peak heating loads, but most of the time they operate at part-load, which reduces efficiency. CCHP plants, which are well suited to district heating, offer much higher source-energy efficiency than conventional power generation. |
| Ability to utilize renewable energy and waste fuel sources | With a district heating system, the heat source can be shifted to renewable-energy sources relatively easily. For example, if a gas-fired CCHP plant is serving a district heat network, additional capacity can be delivered by adding a renewable-energy fired plant (wood chips or landfill methane, for example) on the same heat distribution network. Or, the gas plant can be converted to renewable energy. |
| Reduced risk of fuel spills in and around buildings | Avoiding the combustion of heating fuel in buildings eliminates the risk of fuel spills (primarily a concern with heating oil). With district heating, only hot water enters the buildings, not fuel. At central boiler of CCHP plants, provisions to contain spills can be incorporated into the facility design. |
| Reduced pollution from trucking fuel. | Heating oil and propane are distributed by truck; replacing those energy sources with district heat replaces the trucking energy and pollution with much less (and cleaner) electrical pumping energy. |
| Opportunities for use of exterior space | Eliminating chillers, cooling towers, and packaged air-conditioning equipment may reduce local opposition during permitting, while making that space available for green roofs or green space. |
| Improved health and safety | Keeping fuel combustion out of buildings will protect occupants from combustion products that can cause health problems. |

*Table 4 – Benefits of District Energy Systems – Environmental Benefits – (Wilson, 2007)*

## 6.2 Economic Benefits

Several economic benefits of district energy systems and CCHP that are noted in this report, along with additional benefits are summarized in the following table (Table 5).

| Economic Benefits | |
|---|---|
| Lower first cost to building owner | Eliminating onsite boilers, chillers, or air conditioners from a building can reduce first costs. |
| Lower maintenance costs | Eliminating mechanical equipment from buildings eliminates the cost of maintaining that equipment. |
| Lower cost of heat to the building owner | Particularly if heat is derived from a CCHP plant – in which the distributed heat is a byproduct of power production – the cost per unit of delivered heat may be lower than if heat were generated in individual buildings. |
| Value of space not lost to mechanical equipment in buildings | Heating, cooling, and water-heating equipment takes up valuable space in buildings, especially in commercial buildings, that could otherwise be utilized or rented. Rooftop space not required for cooling towers or packaged air conditioning equipment can be rented for cell towers or used as high-value penthouse or restaurant space, for example. |
| Increased reliability | District energy systems have a history of superb reliability and minimal downtime. Even with natural disasters, district energy systems have usually maintained operation. |

| | |
|---|---|
| Lower cost of fuel at central plant | Central boilers and CCHP plants may be able to use less expensive fuels, such as wood chips (which cannot be used in smaller boilers in buildings). |
| Reduced peak electricity demand | In commercial buildings, replacing electric chillers or air-conditioning systems with district cooling can significantly reduce electric *demand charges*. |
| Fuel flexibility | District heating systems offer the potential to switch fuels, based on cost. |
| Potential to benefit from renewable energy credits | With CCHP plants using renewable fuel (wood chips, landfill methane, etc.), electricity can be sold at a premium to utility companies providing renewable energy credits. |

*Table 5 – Benefits of District Energy Systems – Economic Benefits – (Wilson, 2007)*

## 6.3 Drawbacks and Challenges

Several drawbacks and challenges of district energy systems and CCHP that are noted in this report, along with additional cautions are summarized in the following table (Table 6).

| Drawbacks and Challenges | |
|---|---|
| High first cost | The initial cost of building central heating or CCHP plants and burying district energy pipes is high. |
| Land disruption | Burying district energy pipe disturbs land and may necessitate costly ecological restoration. |
| May diminish the incentive to conserve energy | Inexpensive thermal energy can reduce the motivation to build highly energy-conserving buildings. (In fact, with such buildings, it may be harder to justify district energy systems). |
| May reduce a building's "passive survivability" | Despite a track record of excellent reliability, dependence on centrally distributed energy can increase vulnerability to fuel shortages or distribution failure, particularly if the source of inexpensive thermal energy has reduced the motivation to build highly efficient buildings. |
| Need for coordinated planning and cooperation | Implementing successful district energy systems necessitates a higher level of planning and coordination than is common in North America (except with the electric infrastructure). |
| Inherent resistance to losing control | District energy systems are very successful with "captive audiences" such as university campuses and hospital complexes, but there may be resistance (by some) to giving up control of one's sources of heating and cooling. |

*Table 6 – Benefits of District Energy Systems – Drawbacks and Challenges – (Wilson, 2007)*

## *7. Conclusion*

Alberta is in the enviable position of having a variety of natural resources available to meet its energy needs, including feasible options for renewable energy. As the Government of Alberta looks to implement its Climate Leadership Plan, the use of natural gas as a fuel for generation of electricity, in particular through the use of district energy systems and cogeneration, is a viable alternative for meeting future energy needs. These innovative systems can increase resiliency, improve the efficiency of public buildings and decrease operating costs, encourage economic diversification, all while lowering GHG emissions.

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