Energy Sources and Systems Analysis

40 South Lincoln Redevelopment District

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Meeting Community-Wide Energy Needs with Renewable Energy Sources

The South Lincoln Project

Supported by a U.S. Department of Housing and Urban Development (HUD)/U.S. Department of Transportation (DOT)/U.S. Environmental Protection Agency (EPA) partnership, the Denver Housing Authority (DHA) is leading the redevelopment of the city's La Alma/Lincoln Park neighborhood (South Lincoln). The project includes redeveloping 270 units of existing public housing, along with other sites nearby. When complete, the redevelopment project will encompass more than 900 mixed-income residential units, commercial and retail properties, and open space.

As part of the project planning, the U.S. Department of Energy (DOE) National Renewable Energy Laboratory (NREL) worked with Group14 Engineering of Denver to analyze district energy systems for their potential use in the project.

The analysts estimated the hourly heating, cooling, domestic hot water, and electric loads required by the community; investigated potential district system technologies to meet those needs; and researched available fuel sources to power such systems. To evaluate the economic and environmental viability of each system, the team used the following metrics: simple payback period (SPP), net present value (NPV), and greenhouse gas (GHG) reductions.

Builders, developers, and housing authorities are discovering that using renewable energy to generate energy and heating at the community level may help both the economy and the environment. In addition, economies of scale may make community-based energy system designs even more attractive.

Traditionally, homes and businesses have been heated and cooled building by building. But it is often easier and more cost-effective to design larger "district" (community-wide) energy systems. Potential buyers or renters may also find communities powered by renewable energy more attractive, enabling builders to market their offerings as "green" and possibly command higher revenue from sales and rents. Finally, even if it may not be economically feasible to build district systems at the outset, using "renewable-ready" designs allows renewable energy to be added down the line, as the costs of renewables follow their current downward trends.

District systems have a number of advantages. They are larger, they can capitalize on load diversity within the community, they are reliable and easier to maintain, they can potentially attain high efficiencies by combining electrical generation with heating or cooling or both, and they may offer the community autonomy in terms of the system's fuel source and operation.

This case study outlines the appropriate approach to evaluating any district system, and presents selected results from one such analysis—the South Lincoln Redevelopment project in Denver, Colorado (see sidebar).

Assessing Community Energy Requirements

When planning community energy projects, it's important to start by predicting the hourly heating, cooling, domestic hot water (DHW), and electric energy load and requirements. For the South Lincoln analysis, the electric load includes all building-level uses except for those associated directly with heating and cooling. This includes lighting, plug loads, and HVAC fans. Load is a measure of heating, cooling, DHW, and/or electricity a community needs at any one instant in time. Estimating the community's load enables analysts to predict the amount of fuel expected to be used in a typical year.

Peak demand is the maximum hourly demand for the entire year. For instance, peak heating demand is the amount of heating required to meet the community's needs on the coldest night of the year. Estimating maximum demand allows analysts to determine the appropriate size of a system that can keep up with the community's needs during peak demand periods.

To begin the South Lincoln analysis, the team created building energy models to simulate the expected energy usage of each type of building in the community. These simulations predict hourly energy load and demand for each building type. Simulation results were scaled up to represent the entire community's usage.

All the building areas in the redevelopment project were represented with three models—one of the high-rise residential spaces, one of the low and mid-rise flats (both of these building types were represented with one model), and one of the townhouse units. The team used information from DHA on floor area by space use, number of residential units, and number of bedrooms.

Modeling results indicated that electricity and space heating are the largest community loads, each requiring approximately 5,000 megawatt-hours per year (MWh/yr). Cooling and DHW require approximately 2,500 MWh/yr apiece. The team's results showed that space heating and DHW together represent the dominant thermal load.

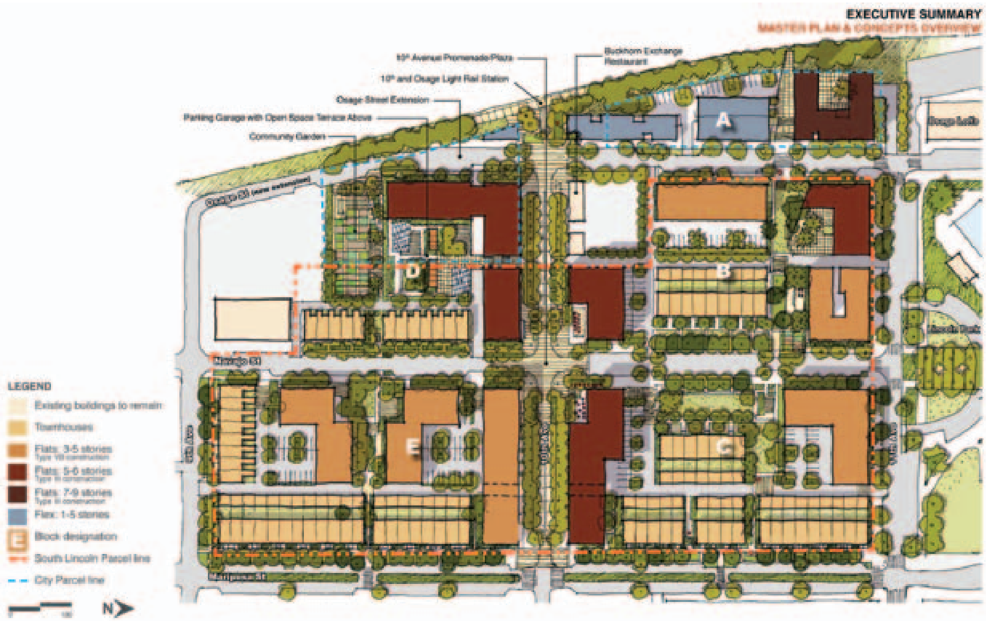
Economic Analysis

Using federal guidelines for rates of discount, electricity escalation, and fuel escalation, the team conducted an economic analysis. The guidelines originated in the federal life-cycle costing requirements developed by the National Institute of Standards and Technology (NIST). The discount rates for 2010 were valid from April 1, 2010, to March 31, 2011.

Using a tool called the Energy Escalation Rate Calculator, the team applied the appropriate escalation rates to natural gas and electricity rates. The values given in this tool are based on Energy Information Administration (EIA) projections. The escalation rates were calculated assuming the project would come online in 2012 and have a lifetime of 25 years.

To calculate the electricity and natural gas rates, the team used a sampling of energy bills for the existing South Lincoln community. The DHA typically uses a commercial utility rate structure for its larger buildings and a residential utility rate for its smaller units. Because the South Lincoln redevelopment is expected to have buildings of both types, average rates were calculated to apply to the entire site.

A federal investment tax credit (ITC) is available for photovoltaics (PV), solar hot water (SHW), biomass, cogeneration and trigeneration, and ground-source heat pump (GSHP) installations. Since DHA is a nonprofit organization, it is not able to directly take advantage of tax credits. However, DHA can still benefit by selling these tax credits on the market or if the systems are owned by a third party. For PV, SHW, and systems powered by fuel cells, the credit is worth 30% of the initial cost of the system. For GSHPs, biomass, and cogeneration or trigeneration systems not powered by fuel cells, the credit is worth 10% of the initial cost of the system. For this analysis, the team looked at cases with and without these incentives.



Artist's rendering of the planned South Lincoln redevelopment project

Greenhouse Gas Emissions Analysis

To examine potential emissions, the team took electricity emissions data directly from the EIA's publication of Colorado's electricity profile. Natural gas emissions data are from the EPA's Climate Leaders Program. Carbon dioxide (CO_2) is by far the dominant GHG emission for both electricity and natural gas, and emissions associated with utility-supplied electricity were found to be nearly five times greater than those from natural gas. These facts play a major role in the final analysis results.

Energy Sources

The source of energy used in buildings and district systems affects the economics, environmental impact, and feasibility of any proposed project. To address local availability, economic implications, environmental considerations, and any pros or cons specific to this project, the team examined several energy source options.

Utility-Supplied Electricity

The existing utility grid will almost certainly play a part in the South Lincoln redevelopment. Although it's convenient, with relatively stable costs, electricity from the local utility carries with it substantial environmental impacts. Because most of Colorado's electricity is generated by coal-fired power plants, significant GHG emissions are associated with its production. In addition, the efficiency of a power plant and its distribution lines is typically around 35%. As a result, 1 kilowatt-hour (kWh) of electricity used in a building requires about 3 kWh of energy from coal. This multiplying effect must be taken into account when calculating electricity's CO_2 emissions.

At the building level, electricity costs depend strongly on the local utility's rate structure. Residential rates tend to have a fairly high electricity consumption charge (in dollars per kilowatt-hour), and typically no demand charge (in dollars per kilowatt). Commercial rates in Colorado, on the other hand, typically have low electricity consumption charges and significant demand charges.

Natural Gas

Natural gas is the conventional fuel source for heating in the Denver area, but it can also be effectively used to generate electrical power. It's in ready supply and many of the systems it can fuel are well-established, off-the-shelf technologies.

Current natural gas rates are relatively low by historical standards. In addition, Colorado has some of the lowest natural gas rates in the nation. The cost of natural gas for the South Lincoln community in the past year averaged to about $0.673/therm. Natural gas prices, however, are volatile, and using natural gas in this project would expose the neighborhood to potentially high fuel prices in the future.

Because burning natural gas releases significantly less CO_2 than burning coal, producing electricity using natural gas will generally result in sizable CO_2 emission reductions. Like coal, however, natural gas is a non-carbon-neutral ("carbon-neutral" means that the fuel has no net CO_2 emissions), nonrenewable resource.

Biomass

Biomass fuel is produced from organic materials such as plants, agricultural residues, forestry by-products, and municipal or industrial wastes. In the Denver area, the most viable biomass options are coarse-ground wood, wood chips, and wood pellets. The primary source for all three is beetle-killed pine, currently a plentiful source and projected to be a stable resource for decades.

In contrast to natural gas and other fossil fuels, biomass is a renewable, carbon-neutral fuel source. Put another way, the organism from which the fuel is derived absorbs approximately the same amount of CO_2 while it's living as it will release during combustion or decomposition. Assuming that the resource is being replaced at the same rate as it's being consumed, the rates of CO_2 emission and absorption will be approximately equal, resulting in near net zero carbon emissions. The energy consumed by transporting the fuel from the source to the point of use results in minor carbon emissions that are not accounted for in this analysis.

Solar

Colorado has a particularly abundant solar resource. The state generally sees few overcast days, and its higher elevation reduces the amount of solar radiation lost while filtering through the atmosphere. No monetary or environmental costs are associated with using the sun for power throughout the life of a system.

District Systems Analysis

The Base Case

To generate a baseline energy usage profile for the South Lincoln redevelopment, the analysis team created a base case. This baseline was used as the starting point for each energy, economic, and emissions analysis. Note that, in district systems analysis, the base case chosen has a significant impact on the results.

Rooftop solar PV installation at the Solar Siedlung in Freiburg, Germany
Photo copyright: Rolf Disch Solar Architecture, Freiburg, Germany.

Base Case Assumptions

The base case used here assumes that heating would be supplied by natural gas boilers with an overall thermal efficiency of 85%. Cooling would be provided by chillers with an overall coefficient of performance (COP) of 3.1. The local utility would furnish electricity. The analysis team applied these efficiencies to the energy requirements predicted by the building energy models to determine the community's baseline energy usage. The annual energy costs and GHG emissions were based on this baseline energy usage. The team found that electrical energy usage, including that used for cooling, plays a significant role in the overall emissions profile.

District Heating

A central biomass boiler can supply clean space heat and DHW for a district. Such a plant requires infrastructure like a building to house the boiler and the fuel, along with a road that allows easy access for fuel-delivery trucks. A natural-gas-fueled backup system should also be installed, which significantly increases the up-front cost as well as the SPP of the central boiler. Finally, a central biomass plant typically requires an operator much of the time, resulting in high operations and maintenance (O&M) costs and further lengthening the system's SPP.

Because a district biomass system requires large volumes of fuel to be delivered regularly, the site must be prepared for this increased traffic. For South Lincoln, the team performed an initial analysis to determine the approximate number of tractor-trailer loads of wood chips required per week to meet the proposed community's heating and DHW loads. During the peak heating season, the results indicated that about six tractor-trailer loads per week would be sufficient. At other times of the year, fewer numbers of loads would be needed.

The analysis team examined three biomass system sizes based on the heating demand of the community, using SPP to determine an optimal system size. For each analysis, wood chips were assumed to be the fuel of choice.

Cogeneration and Trigeneration

A cogeneration system performs two functions simultaneously, and a trigeneration system performs three at the same time. In either type of system, waste heat can be recovered and used for electricity, heating, and cooling, greatly increasing the system's total efficiency. Combined heat and power (CHP) systems, in which the waste heat created during electricity generation is used to meet space heating, DHW, or industrial needs, are the most common types. Only CHP systems were analyzed in this study.

A cogeneration or trigeneration plant can be driven by gas turbines, internal combustion (IC) engines, or fuel cells. For the South Lincoln site, natural gas is the most appropriate fuel for all of these technologies because it has the lowest cost.

The size, or capacity, of a system can have a great impact on its economic viability. Make the system too large, and it's likely to produce more thermal energy or electricity than the community can consume at a given time, wasting energy and money. Make it too small, and economies of scale will suffer because the up-front cost of the distribution system is virtually the same for large and small cogeneration plants.

The team analyzed each technology based on three different capacities: (1) a larger size that's projected to meet most of the community's thermal loads; (2) a smaller size based on the lower size limits of most technologies; and (3) an optimal size based on the SPP analysis. Note that the optimal size may be smaller than is commonly available.

The monetary and environmental savings seen with cogeneration systems are mostly tied to electricity production. Utility-supplied electricity tends to be fairly expensive and is primarily generated using a high-emissions fuel like coal. The efficiency with which a cogeneration system can produce electricity, then, is important. Overall efficiencies, which include the useful thermal energy produced, are generally of secondary importance.

Like cogeneration, system size and efficiency of electricity production have a significant impact on the economics of a given trigeneration installation. Trigeneration systems, though, have a greater ability to use the thermal energy produced by a system. In addition, when a trigeneration system uses thermal energy to deliver cooling, it's effectively replacing the electricity that would otherwise have been used for that purpose. In this way, larger system sizes become more feasible.

Gas Turbine Cogeneration

A gas turbine combusts a gaseous fuel—like natural gas—to produce energy, which drives a high-pressure flow of air through a turbine. The turbine then generates electricity. The primary advantage of a gas turbine is its high overall efficiency. Of the technologies considered, the gas turbine generally has the highest efficiency when both electricity and useful thermal energy are taken into account. Gas turbines have relatively low efficiencies, though, when considering only electric production at smaller capacities (less than 5 megawatts [MW]). This is a severe disadvantage. Gas turbines also have fairly high up-front costs at smaller capacities.

Fuel Cell Cogeneration

A fuel cell produces electricity through an electrochemical cycle. The mechanism used to produce power is similar to that of a typical battery, but a fuel cell uses an open cycle in which the fuel can be continuously supplied. Fuel cells can use hydrocarbon fuels like natural gas, but the fuel isn't burned as in an IC engine or gas turbine. Although fuel cells generally have the highest electrical efficiencies of the technologies considered, they typically have the highest up-front costs as well. Overall efficiencies are on par with IC engines.

Internal Combustion Engine

Although IC technology also relies on gaseous fuel combustion to power an engine or generator, an IC engine uses a different thermodynamic cycle than a gas turbine. Internal combustion is a common and well-established technology with well-understood maintenance and performance issues. The two main advantages of the IC engine are its relatively low initial cost and high electrical efficiency. In addition, this technology tends to have the lowest O&M of the technologies considered.

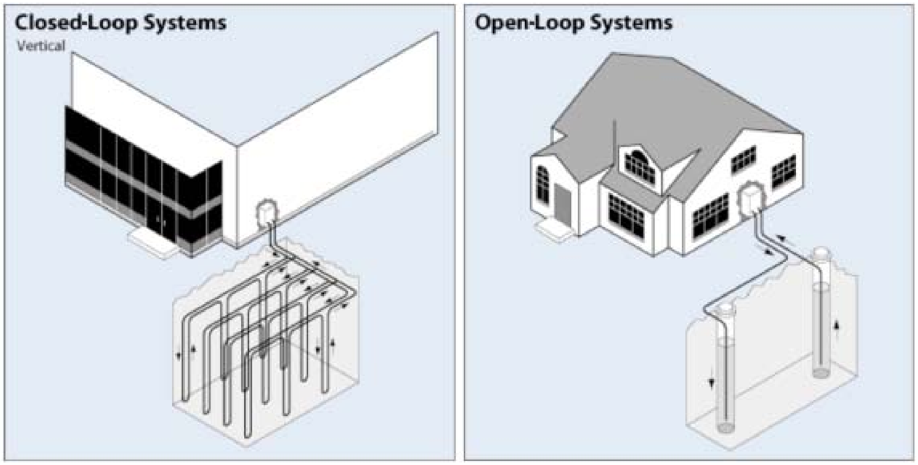
Ground-Source Heat Pump

A GSHP uses the stable temperatures of the ground or ground water to extract heating or cooling for space conditioning. It pulls heat out of the ground when in heating mode, and dumps heat into the ground when in cooling mode. GSHPs typically have high efficiencies for both heating and cooling, and use electricity as the only fuel source. GSHPs are sometimes referred to as geothermal heat pumps; the two terms are synonymous.

To accurately assess the thermal potential of the soil at a project site, test boreholes must be drilled, followed by thermal testing. Phase 1 of the South Lincoln redevelopment included borehole drilling and thermal testing, and the results may be used for the rest of the site because ground conditions are similar across the site.

GSHP systems are most effective when a community's heating and cooling needs are well balanced over the course of a year. This allows the ground to "recharge" and avoids a slow increase or decrease in soil temperature over time. The South Lincoln site presents a challenge in that the community's heating needs are far greater than its cooling needs.

Although GSHP systems are highly efficient, their use of electricity as the fuel source for both heating and cooling can result in marginal GHG reductions. Although CO_2 emissions are typically reduced when the heat pump is being used for cooling, the emissions can actually increase in heating mode because in the absence of a GSHP, natural gas is typically the fuel source for heating. Because the emissions associated with electricity in Colorado are so much higher than those for natural gas, heating with electricity, even at the high efficiencies seen from GSHPs, often results in increased CO_2 emissions. South Lincoln would require significantly more heating than cooling, making the net GHG savings from using a district GSHP marginal.



Closed- and open-loop GSHP systems

Photovoltaics

PV systems use only sunlight as a fuel source and produce only electricity. PV is a well-established and reliable source of electricity that tends to have fairly high up-front costs but low O&M costs. Installed costs for PV have dropped dramatically in the last decade, however, and this trend continues. To successfully implement PV at South Lincoln, rooftops and parking areas would have to be thoughtfully designed to maximize solar access.

For this analysis, the team investigated two primary scenarios: one in which all suitable rooftop area is used for PV and carports are built on which to mount solar panels, and one in which only the suitable rooftop area is used. The team analyzed each option for panels with efficiencies of 15% and 19%. Additional analyses examined the effect of installing one large PV system versus multiple smaller systems. Dividing the installations into several smaller projects allows entry into a lower tier in the Xcel Solar*Rewards Program (see sidebar) and takes greater advantage of the program's up-front rebates.

Solar Hot Water

SHW systems are designed to produce useful thermal energy using only the sun as the energy source. An auxiliary heat source is typically needed for a consistent supply of DHW. Like a PV system, an SHW system requires rooftop space on which to mount the solar collectors. Any area that's used for SHW cannot be used for PV, and vice versa. The team did an analysis to determine the optimal mix of SHW and PV under the assumption that all viable rooftop area with solar access would be used. The results showed that using 100% PV and 0% SHW gave the highest NPV and the greatest GHG savings. The economics of these technologies, though, are highly dependent on incentives and funding methods (see sidebar).

As an SHW system increases in size, its overall effectiveness generally diminishes because it begins producing more hot water than the building can use at certain times of the year. For this reason, SHW systems are typically sized to meet 70% to 80% of the building's total DHW load.

Funding PV Systems

PV installations can be funded in a number of ways. For this analysis, the team assumed that DHA would purchase and own the system. In this scenario, DHA could take advantage of Xcel Energy's Solar*Rewards incentives—but not the 30% ITC—on the up-front cost of the system or other tax incentives.

As an alternative to purchasing the PV system, the site could host the system under a third-party power purchase agreement (PPA) structure. In this structure, a third-party private entity (or entities) installs, operates, maintains, and owns the PV system on the site property. The site owners would sign a PPA and commit to purchasing electricity from this third party for a fixed amount of time, usually 10 to 25 years. The PPA could include a price escalator that would increase the cost of the electricity at a fixed rate each year over the life of the contract. This rate is usually between 0% and 4%.

The contract would be set up such that the DHA would sign a 20-year contract with the third party, and the third party, in turn, would sell the electricity to the site. DHA would have the option to "buy out" the PPA and become the system owner at any point after year 6. The third party would benefit from the 30% federal ITC and system depreciation, as well as any state and utility incentives. These tax benefits and incentives reduce the installed cost of the PV system, which would translate into competitive electricity rates for DHA.

The team performed energy and economic analysis assuming an SHW system sized to meet 80% of the South Lincoln community's annual DHW load. This system would require about 90% of the total roof area deemed suitable for solar panels.

Conclusions and Recommendations

Table 1 summarizes the results for selected systems from each of the technologies analyzed. The results shown here were selected based on SPP and feasibility of size. Although all results are not reported in this table, it gives a representative comparison of the various district systems.

Table 1. Summary of Analysis Results for Selected District Systems (all results shown include the ITC)

Technology	Size (kW_e/ kW_t)	SPP (years)	NPV ($K)	Total CO_2 Equivalent Saved (%)	Initial Investment per Ton CO_2 Equivalent Saved ($/ton)
Cogeneration					
Natural Gas Turbine	250/409	75.4	–573	8	1,356
IC Engine	300/300	29.2	–200	12	778
Fuel Cell	700/311	33.9	–1,191	33	1,177
Trigeneration					
Natural Gas Turbine	250/409	73.9	–747	9	1,568
IC Engine	350/350	32.3	–332	14	865
Fuel Cell	850/378	34.8	–1,555	41	1,211
GSHP					
GSHP	100% of Load	70.6	–3,744	4	18,894
Biomass Heat					
Wood Chip Boiler	40% of Heating Demand	99.7	–1,351	21	1,106
PV					
Solar Panels (19% efficient; rooftops and carports)	252,455 ft^2 (as multiple smaller systems)	45.2	–10,285	76	2,980
Solar Panels (15% efficient; rooftops only)	188,848 ft^2 (as multiple smaller systems)	38.9	–4,949	46	2,568
SHW					
Flat Plate Panels	80% of DHW Load	88.8	–12,265	6	18,448

Notes: kW_e = kilowatt-electric; kW_t = kilowatt-thermal

Although none of the district systems investigated show favorable economics for the South Lincoln project, some options may make sense as integral parts of the final solution to meet a goal of reducing GHG emissions. The team strongly recommends, however, that electrical, heating and DHW, and cooling loads should be reduced as much as possible before any district system is implemented. Electrical loads can be reduced by combining building system design elements (e.g., high-efficiency lighting, pumps, and fans; timers on bathroom vents; daylighting design); appliance efficiency standards; occupant education (e.g., to turn off the lights when not in use); and any number of occupant incentives such as rewards for using less energy. Heating loads can be reduced primarily through building design, including insulation levels and window specifications. DHW loads can be reduced by educating the occupants (e.g., to do laundry in cold water), using low-flow fixtures, and energy recovery.

Reducing cooling energy use may be among the greatest improvements in the district's baseline energy use. The Denver climate is ideal for natural ventilation, direct cooling with outdoor air, nighttime precooling, and evaporative cooling. These technologies could conceivably almost eliminate conventional cooling methods in the South Lincoln community, significantly reducing the electricity used for cooling.

For this community, the most drastic reductions in GHG emissions would be achieved using a combination of PV for electricity and biomass for heating and DHW. If cooling and other electrical loads could be reduced as recommended, the community might be able to reach net zero GHG emissions by installing 19% efficient solar panels on rooftops and carports and installing a biomass heating system sized to 40% of peak heating and DHW demand. In this scenario, heating and DHW would require some natural gas input. With the reductions in cooling and other electrical energy, however, the PV system is projected to produce enough surplus electrical power to offset the GHG emissions from the site's natural gas usage. Although the economics of buying and owning a PV system might be prohibitive, entering into a PPA could make such a system viable.

Another alternative would be to install PV to offset electricity use, concentrate on reducing heating/DHW loads, and use high-efficiency natural gas systems at the building level in lieu of a central biomass plant. Even though the community would not be expected to reach net zero GHG emissions in this scenario, emissions savings of about 80% or higher are achievable. In addition, up-front costs and O&M costs would be significantly lower. This approach would be much simpler and less costly to design and implement phase by phase, with a relatively small loss of environmental benefit. Considering both economics and environmental benefits, this may be the most reasonable option for South Lincoln.

A third possibility would be to build a cogeneration or trigeneration plant driven by an IC engine or a fuel cell to supply a portion of the community's heating and electricity needs. These systems show the most attractive economics of any of the systems analyzed. A cogeneration plant could be supplemented with PV as a path to net zero emissions. A cogeneration or trigeneration strategy would require more planning and ongoing O&M work by DHA than a PV strategy, though. In addition, a PV system can be installed under a PPA, but a PPA for a cogeneration plant would require the utility's consent. Because the utility has little incentive to agree to this type of arrangement, approval of a cogeneration plant PPA is unlikely.

The team does not recommend SHW systems or a district GSHP system for this project. Both of these systems show poor economics and minimal savings in GHG emissions. Even though some trigeneration systems show comparatively good economics and GHG reductions, these systems are not recommended because reductions in cooling loads and cooling energy use, if realized, would make district cooling unnecessary. Finally, the same issues noted for cogeneration systems apply equally to trigeneration systems.

For More Information

Database for State Incentives for Renewables and Efficiency (DSIRE). "Business Energy Investment Tax Credit (ITC)." *http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=US02F&re=1&ee=1*. Accessed May 9, 2011.

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